MIPS Early Results and Questions for MIRI & SAFIR

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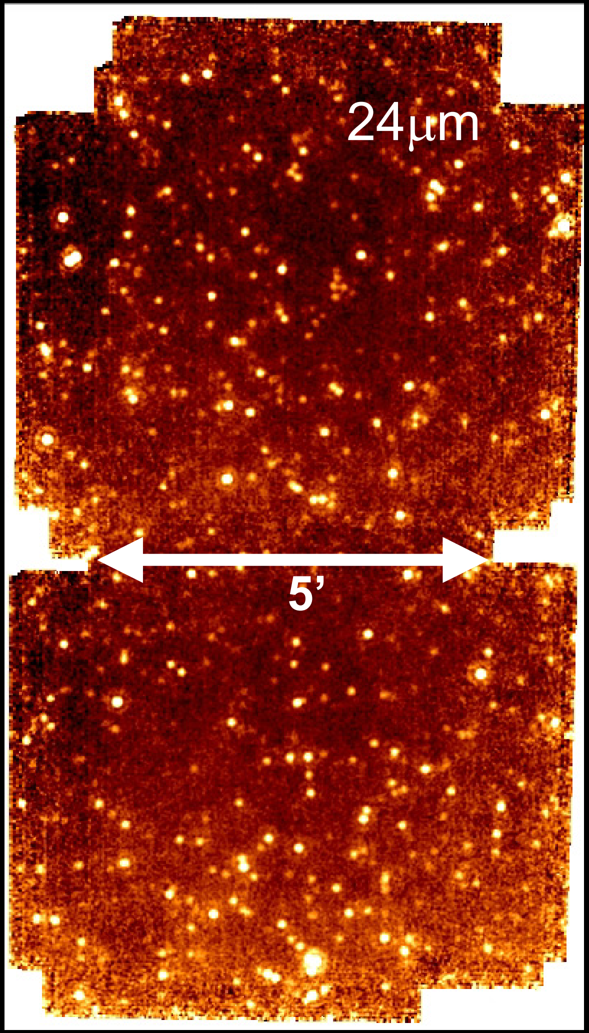
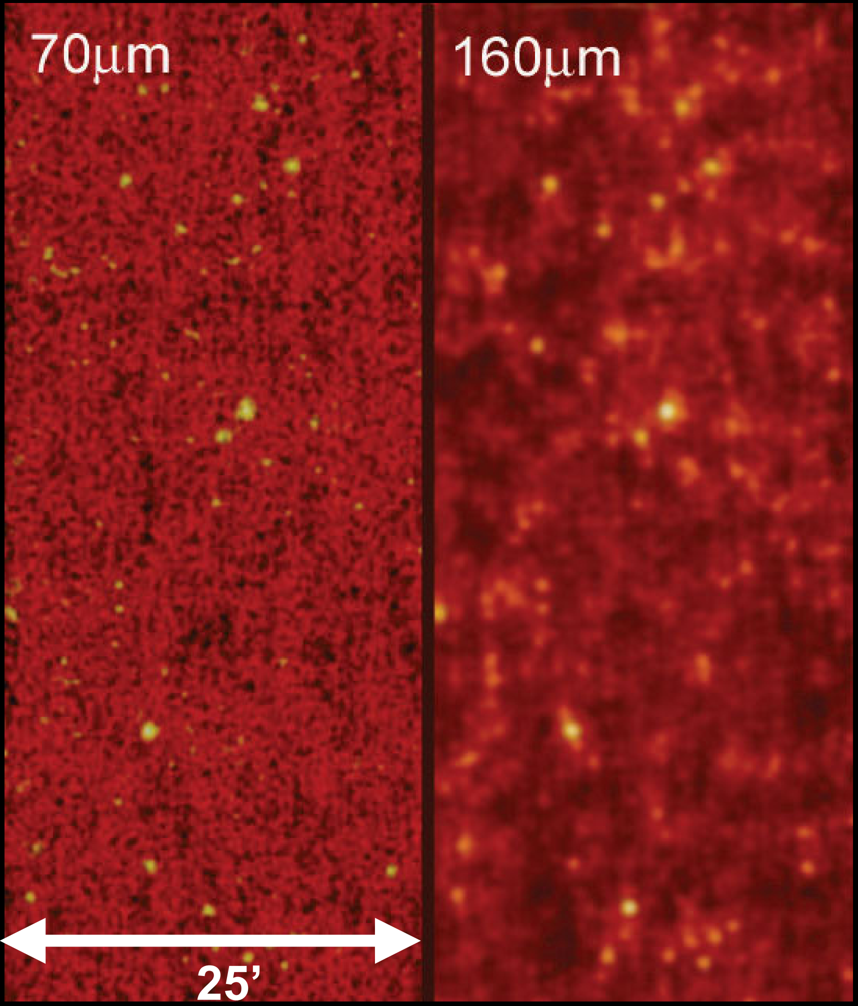
June 7, 2004

From Spitzer to Herschel and Beyond

- Imaging with Nyquist sampling and good photometric behavior brings new possibilities to the far infrared
- Cas A - Textbook example of cosmic ray acceleration
- M33 - What heats the dust?
- Massive galaxies in the very high redshift Universe

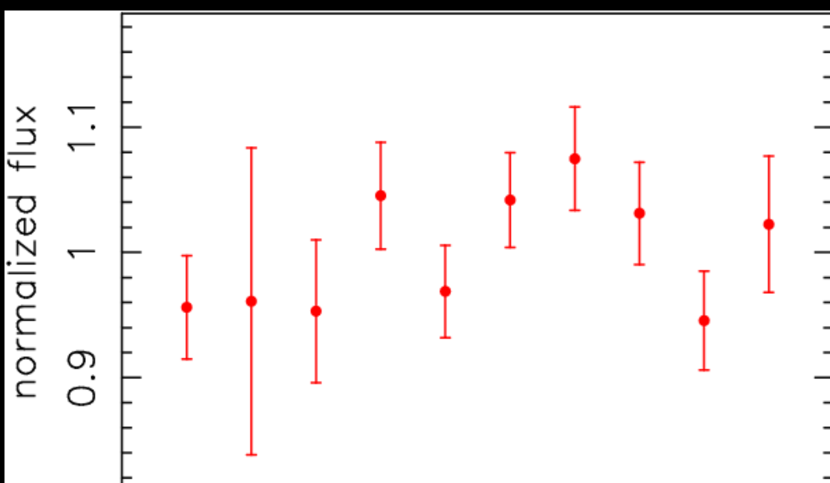




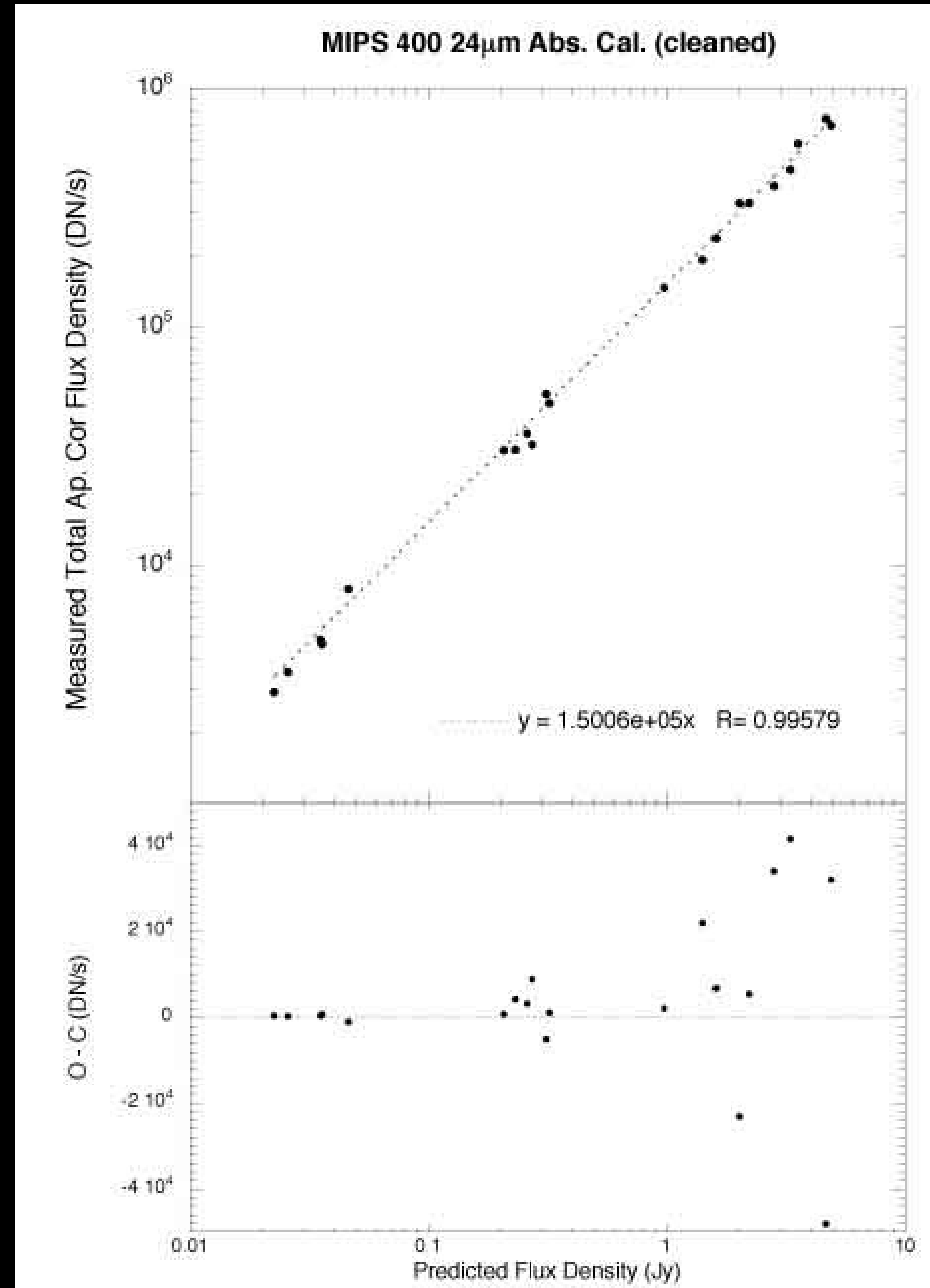
MIPS provides more accurate photometry than we are accustomed to in this spectral range:

24µm shows 1% or better photometry, over large dynamic range (to right).

• 70µm gives ~ 5% rms repeatability (below).

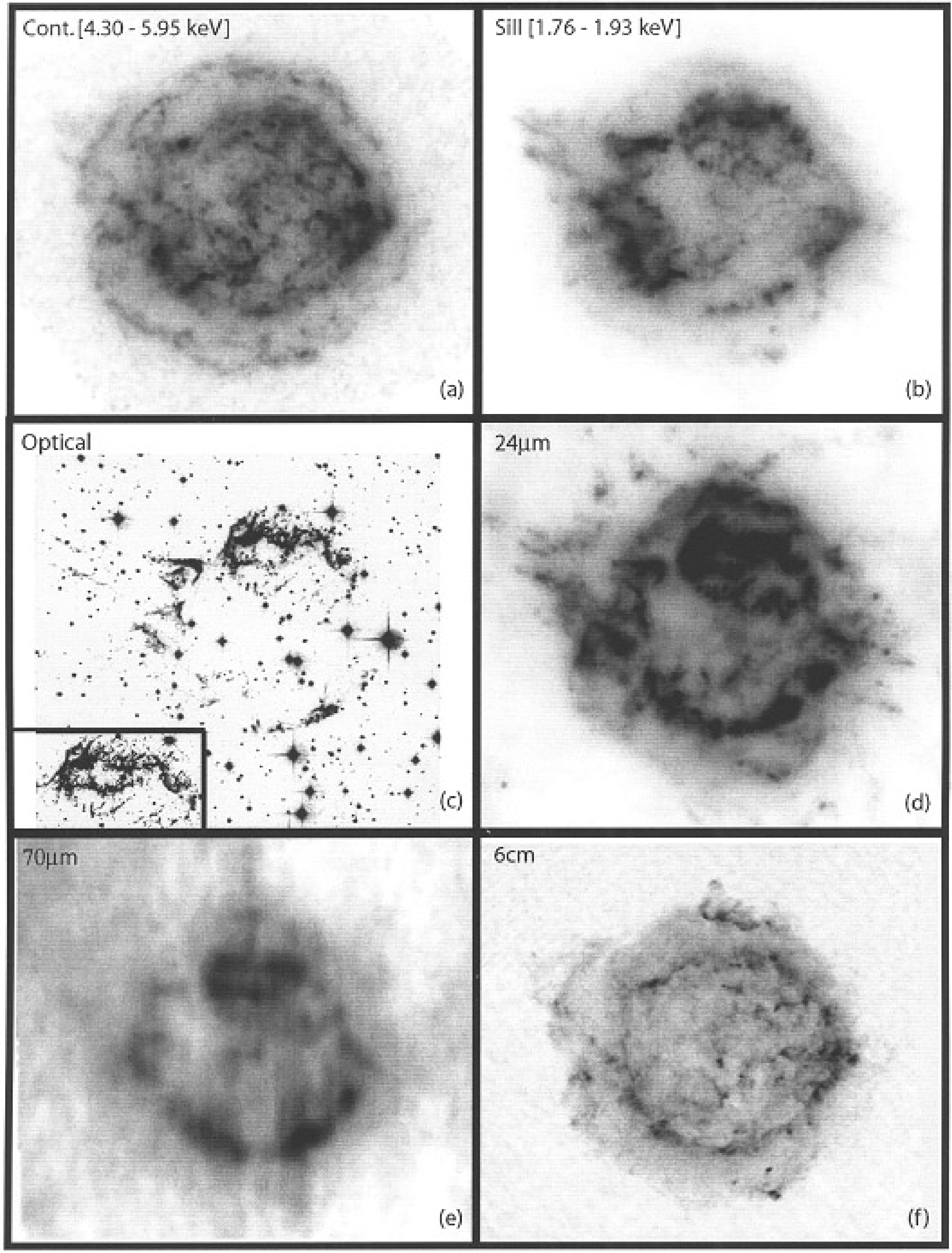


Ten measurements of the K2III star HD 163588 at 70µm, distributed over seven campaigns

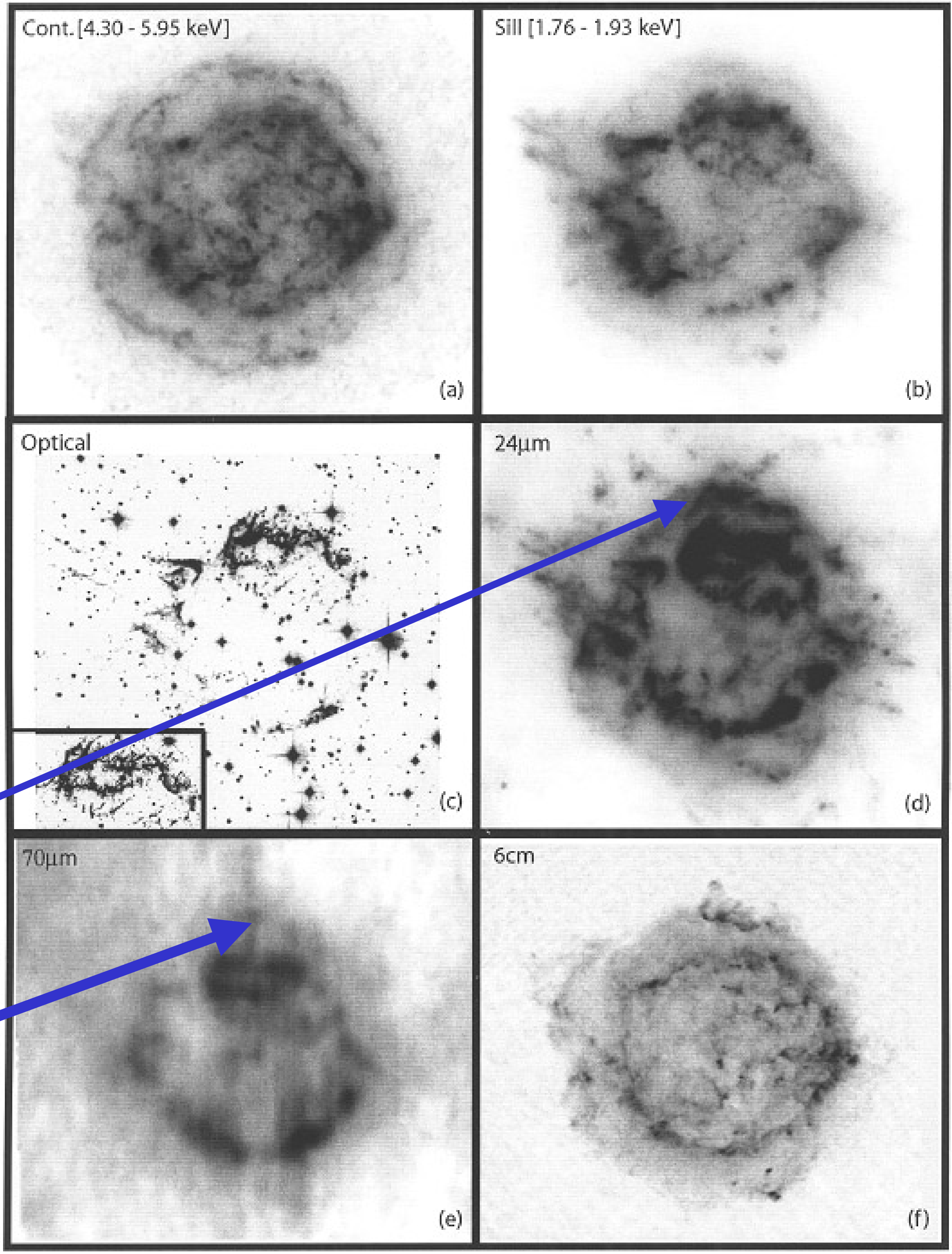


Cas A

Infrared is similar at 24, 70μm (and to ISO 10μm), showing that we are seeing stochastic heating of small grains in hot X-ray emitting plasma. The dust seems to form in the relatively cool gas indicated by emission lines (the optical image is dominated by emission lines).



Cas A

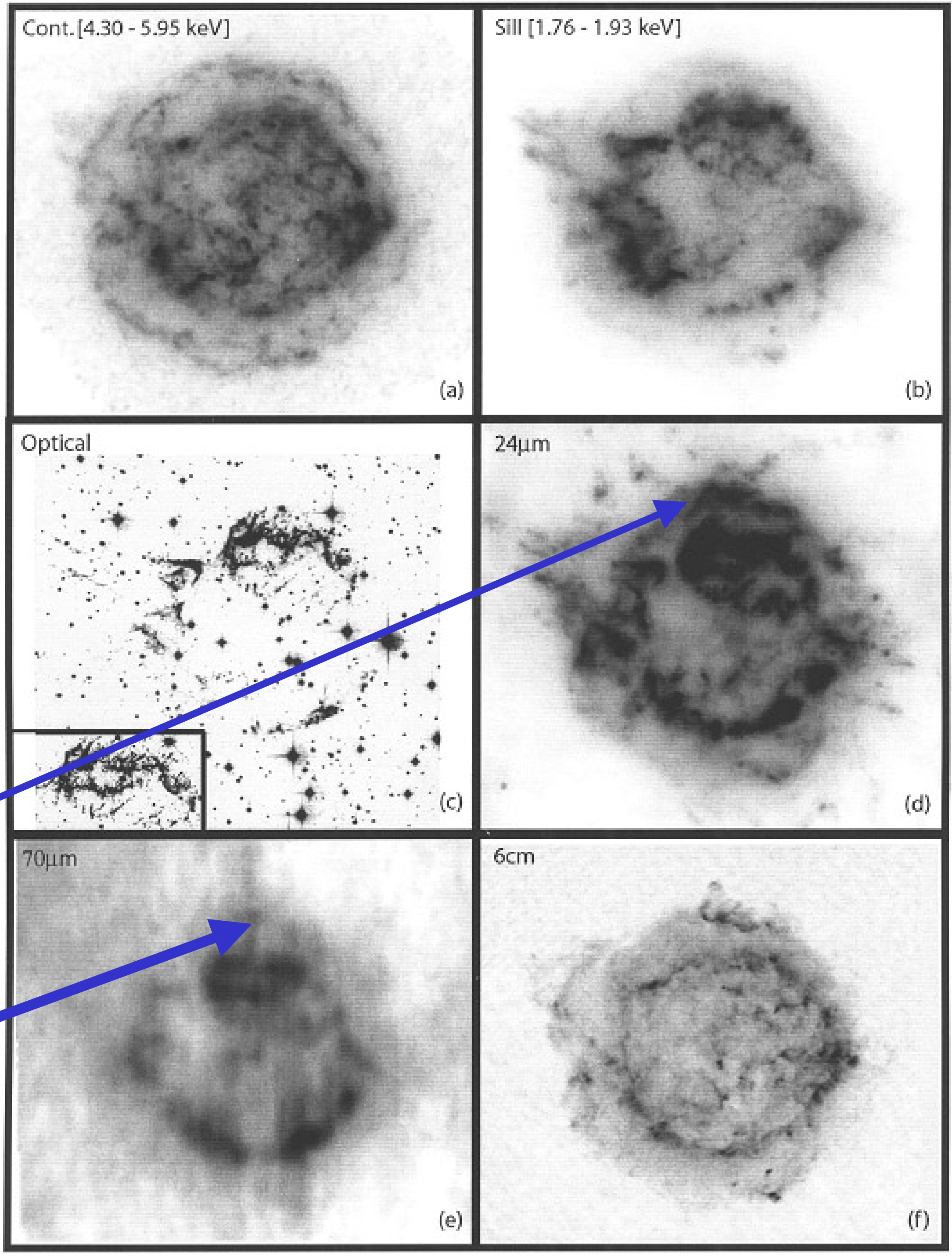


However there is an arc of emission to the north at 24µm that does not follow this morphology. Unlike the rest of the dust, this region is relatively faint at 70µm (and has a unique infrared emission line spectrum).

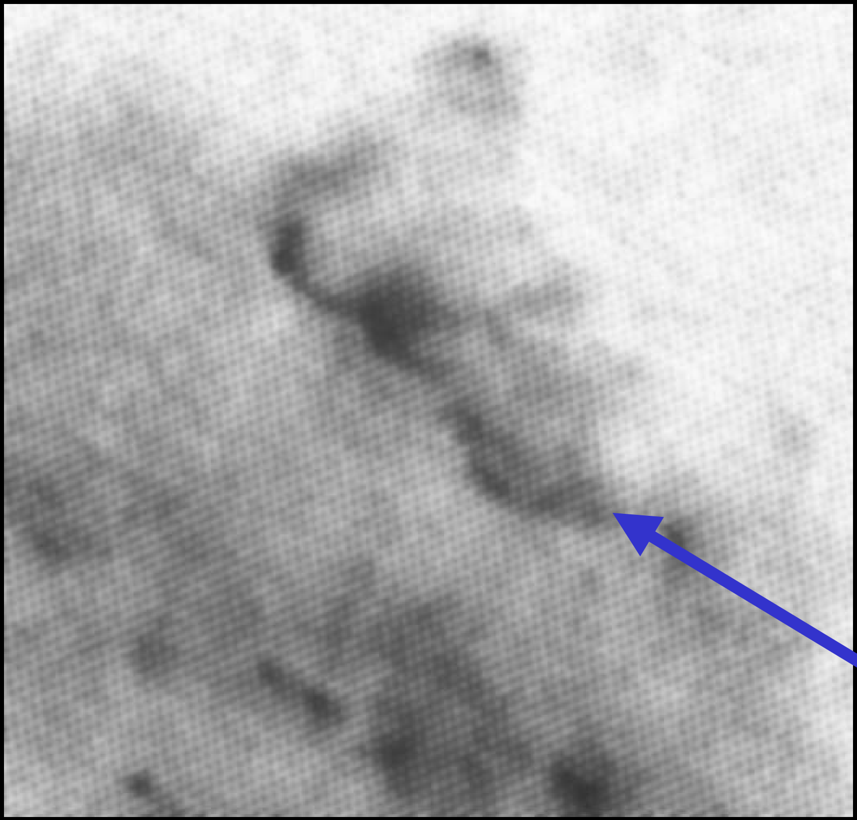
Cas A

Studying such regions is a powerful application of MIRI and SAFIR.

However there is an arc of emission to the north at 24µm that does not follow this morphology. Unlike the rest of the dust, this region is relatively faint at 70µm (and has a unique infrared emission line spectrum).



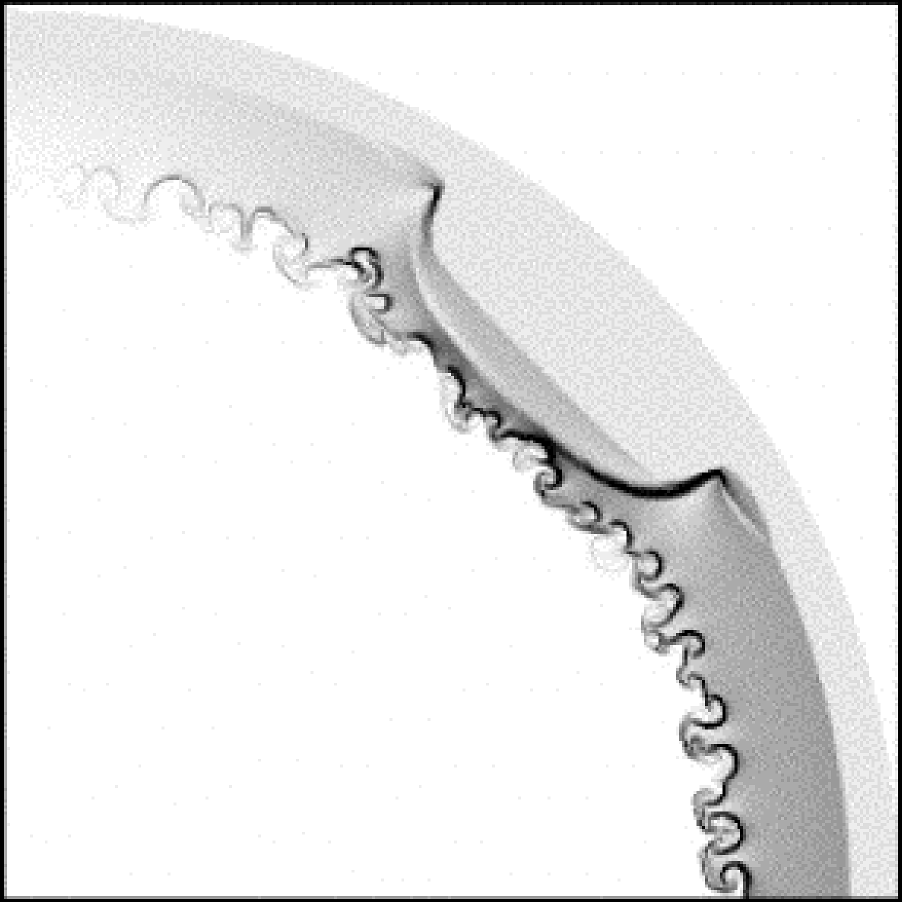
The arc is where the forward shock is encountering a ~ 600 M_{sun} molecular cloud.



Nonthermal radio emission at the shock front/molecular cloud interface.
(We rotate the radio image by 30^{o} to compare with theoretical calculations.)

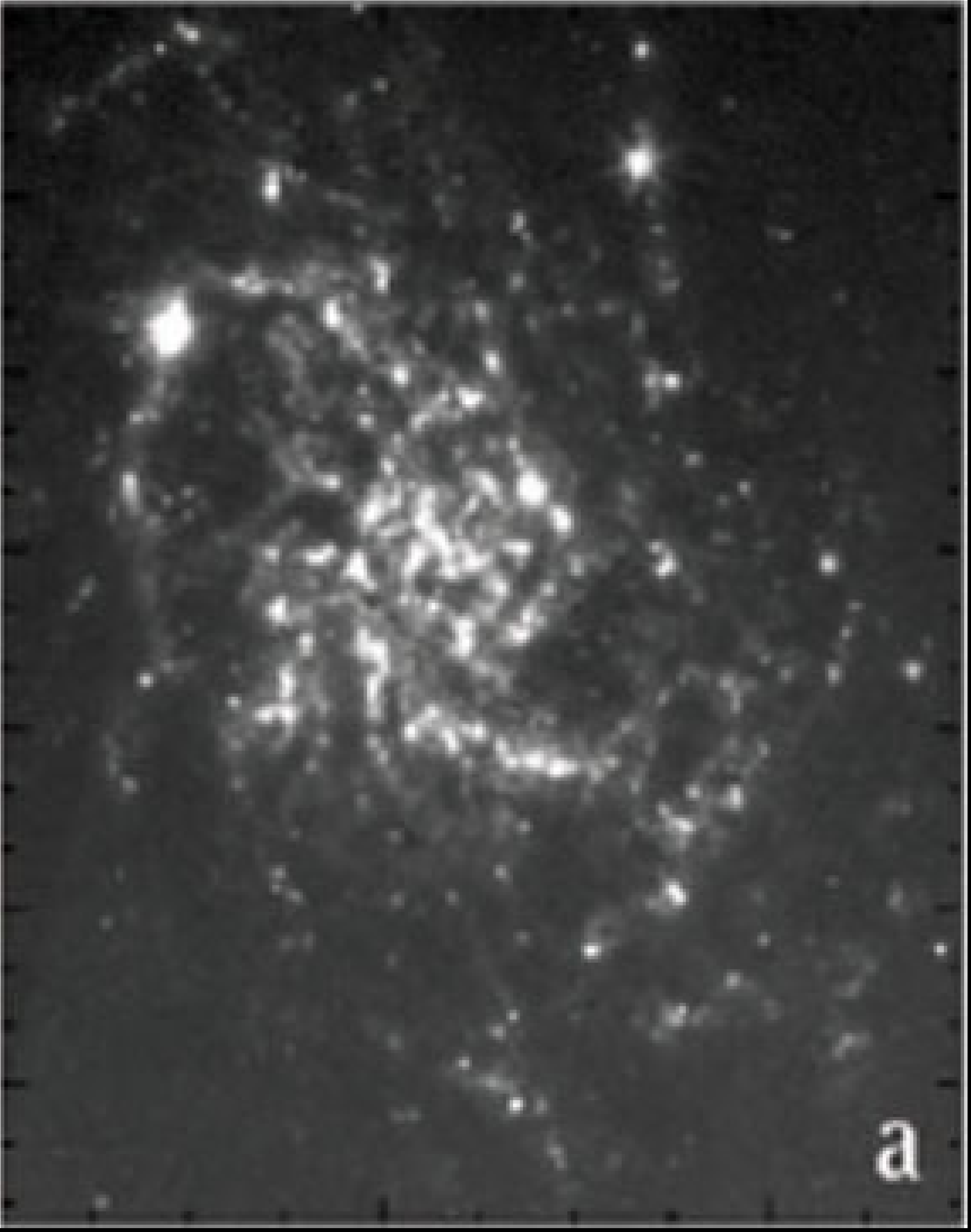
Calculated nonthermal radio emission at a shock front/molecular cloud interface @ 200 years (Jun & Jones, 1999, ApJ, 511, 744)

Enhanced radio emission results from compression and strengthening of the magnetic field at the interaction --



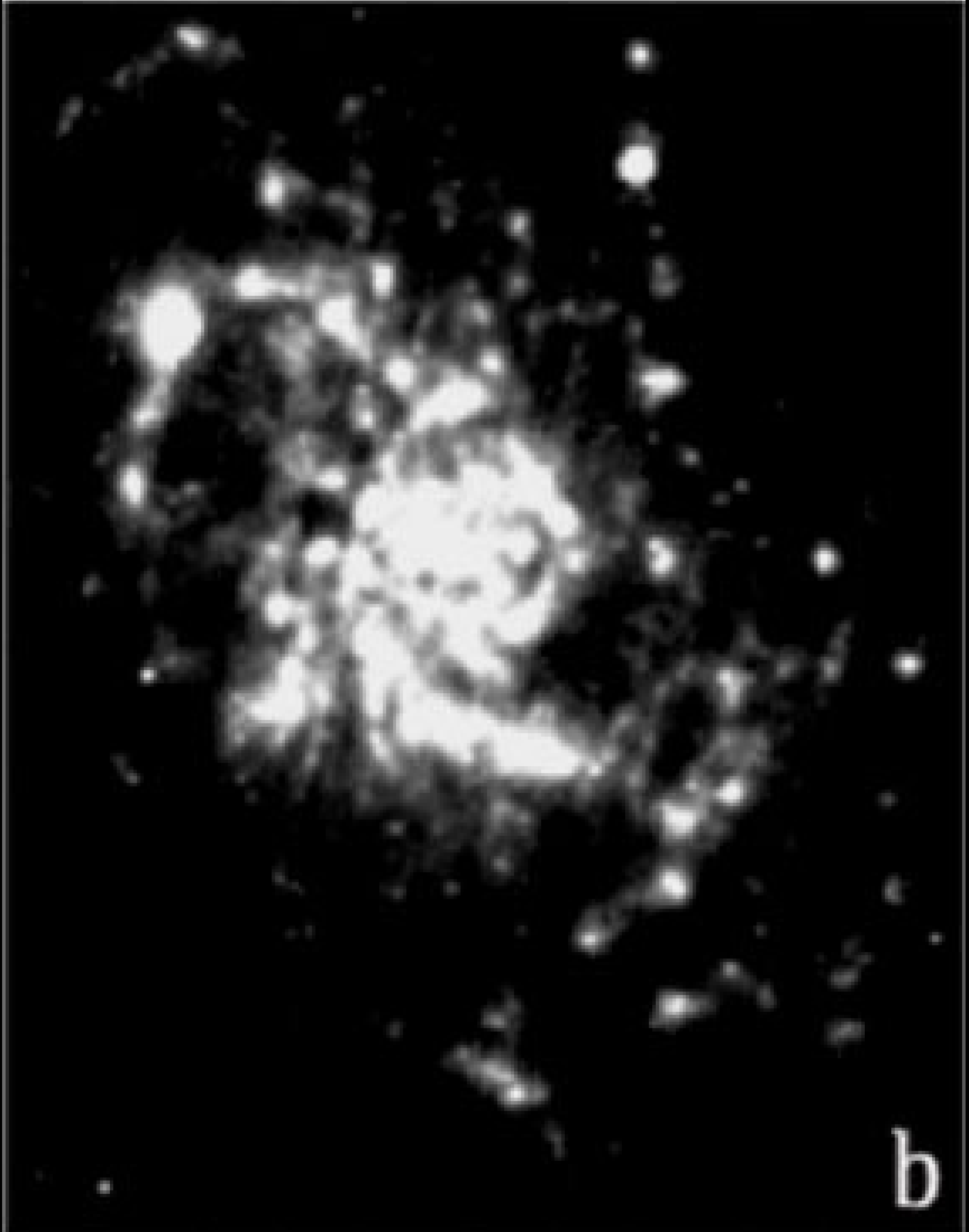
Magnetic field strength at a shock front/molecular cloud interface @ 200 years (Jun & Jones, 1999, ApJ, 511, 744) as well as electron acceleration due to the increased turbulence.

Relativistic electron number density at a shock front/molecular cloud interface @ 200 years (Jun & Jones, 1999, ApJ, 511, 744)

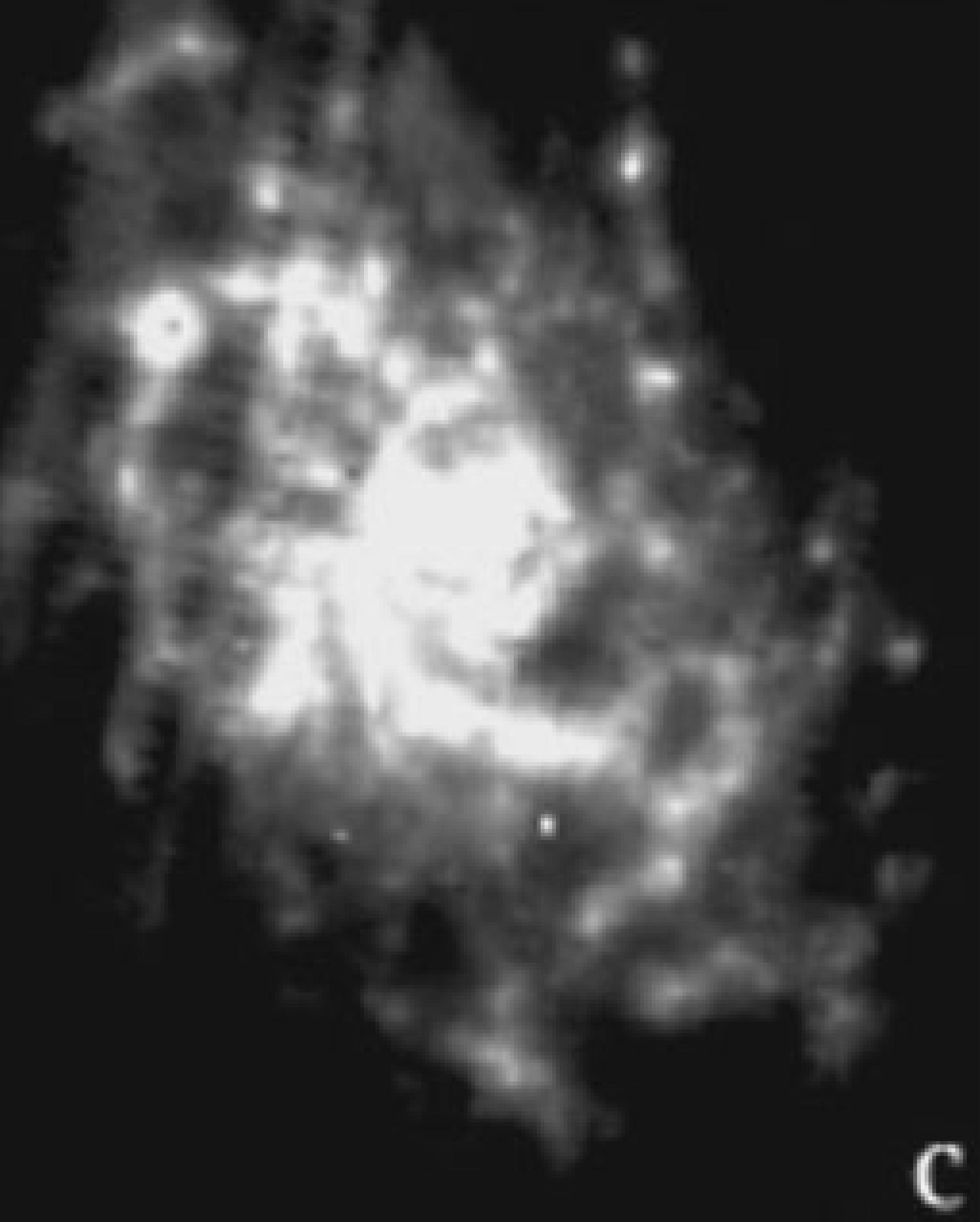


What Heats the Dust in Galaxies?

M33
$24\mu m$

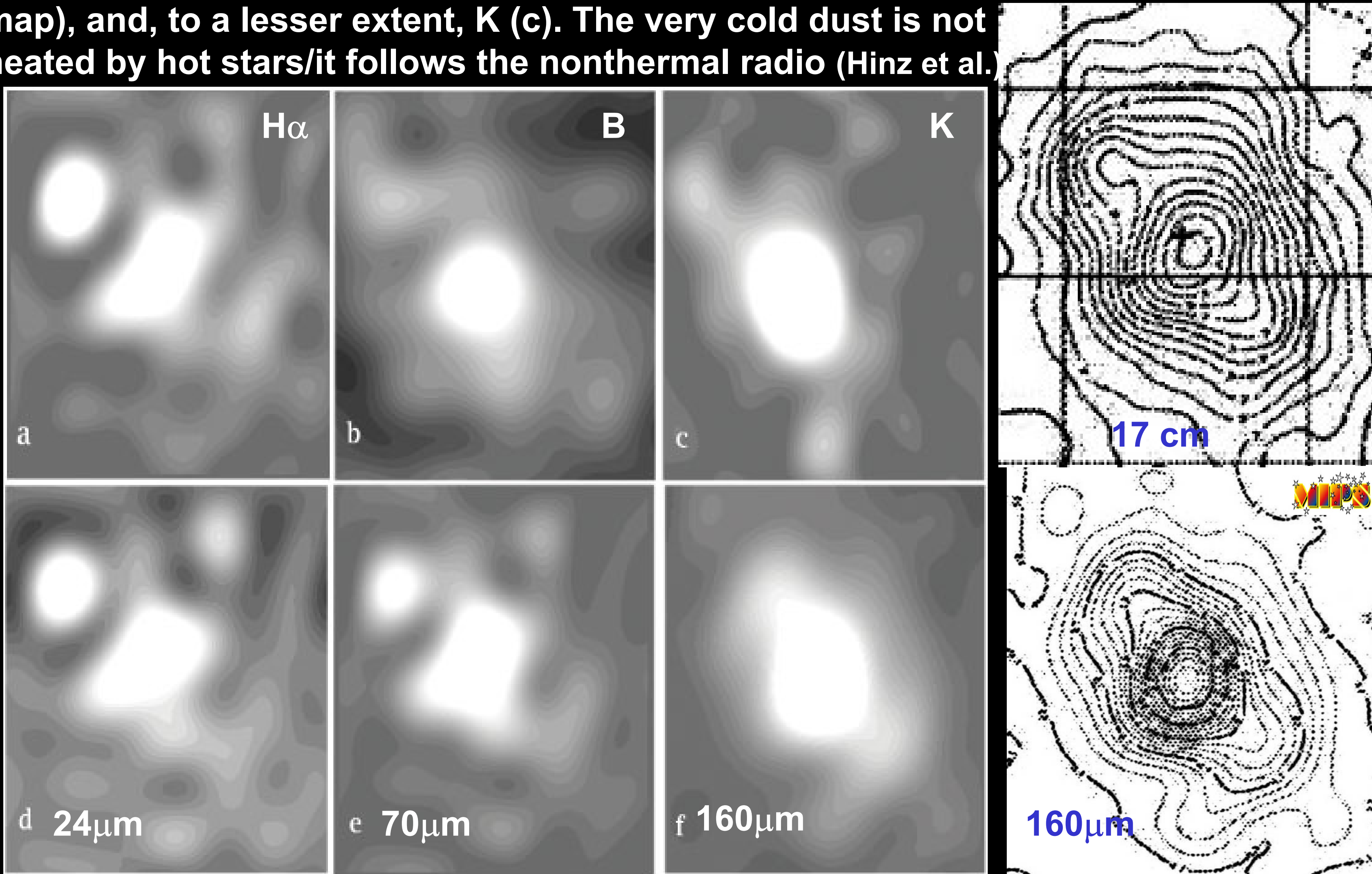


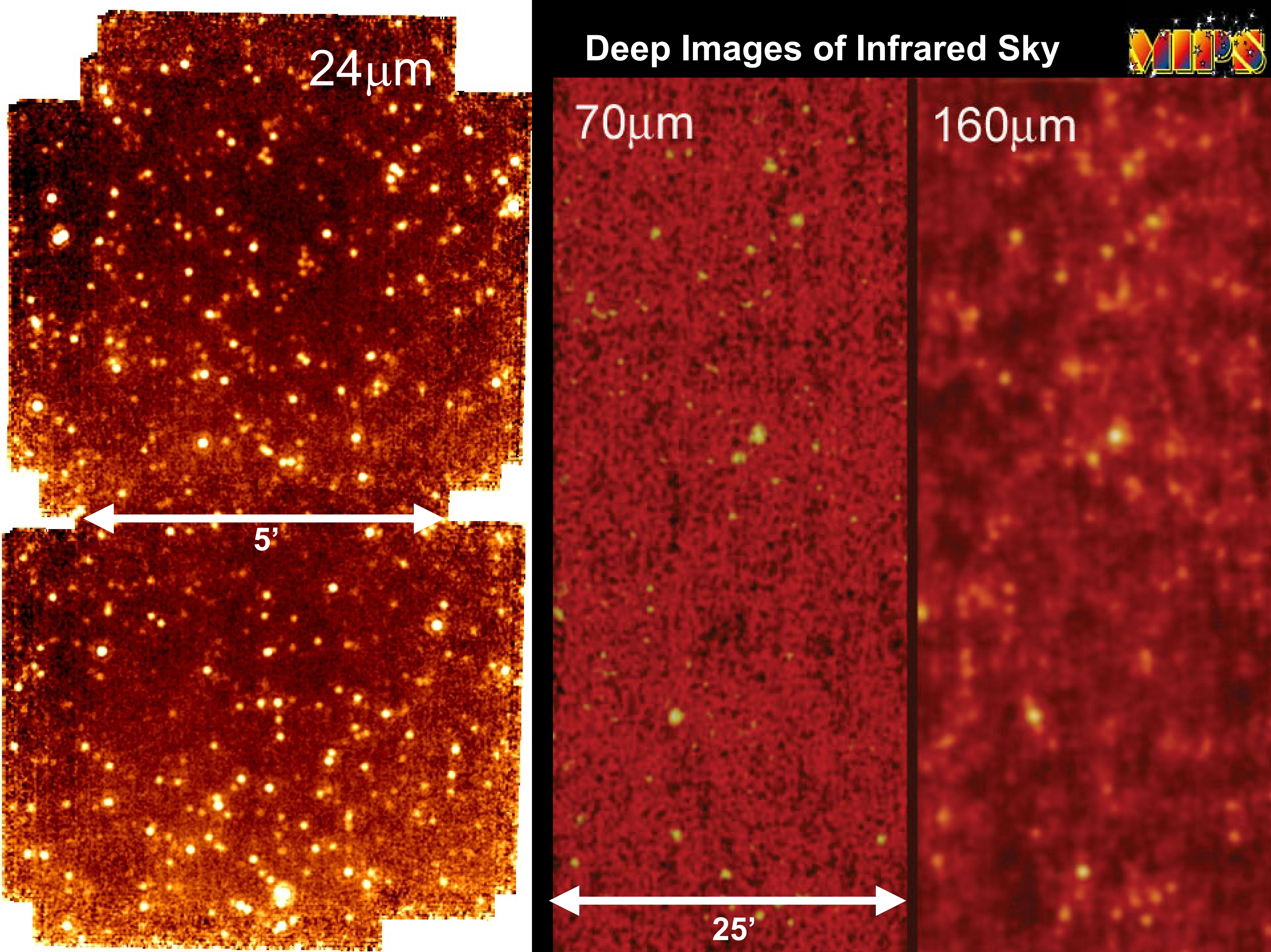
M33
70μm



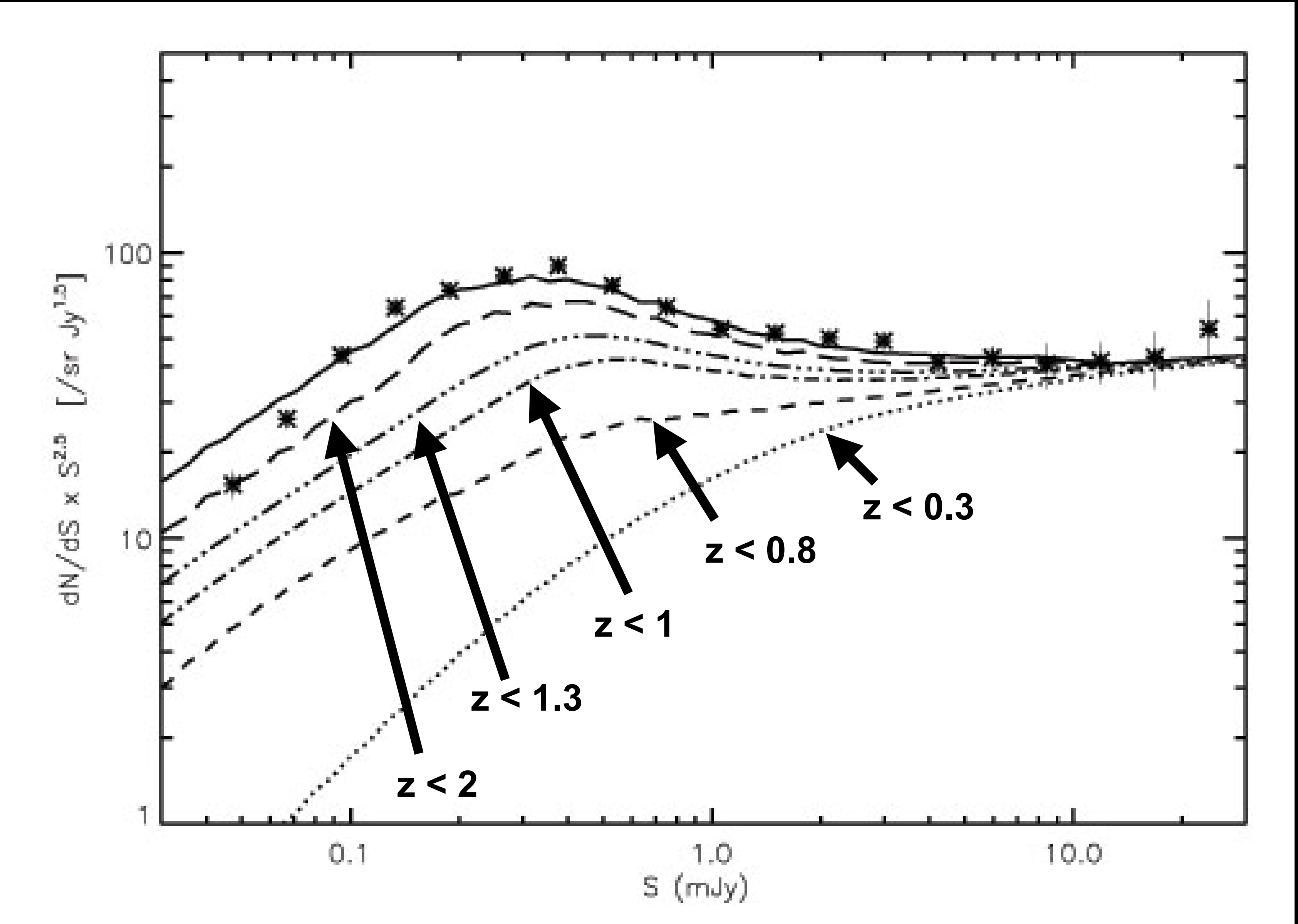
M33
160μm

We isolate the diffuse emission in various bands by low pass Fourier filtering: Hα (a), 24μm (d), and 70μm (e) are very similar, implying heating at the latter two wavelengths by ionizing stars. B (b) and K (c) look quite different. 160μm (f and lower contour map) is different from all except non-thermal radio (upper contour map), and, to a lesser extent, K (c). The very cold dust is not heated by hot stars/it follows the nonthermal radio (Hinz et al.)

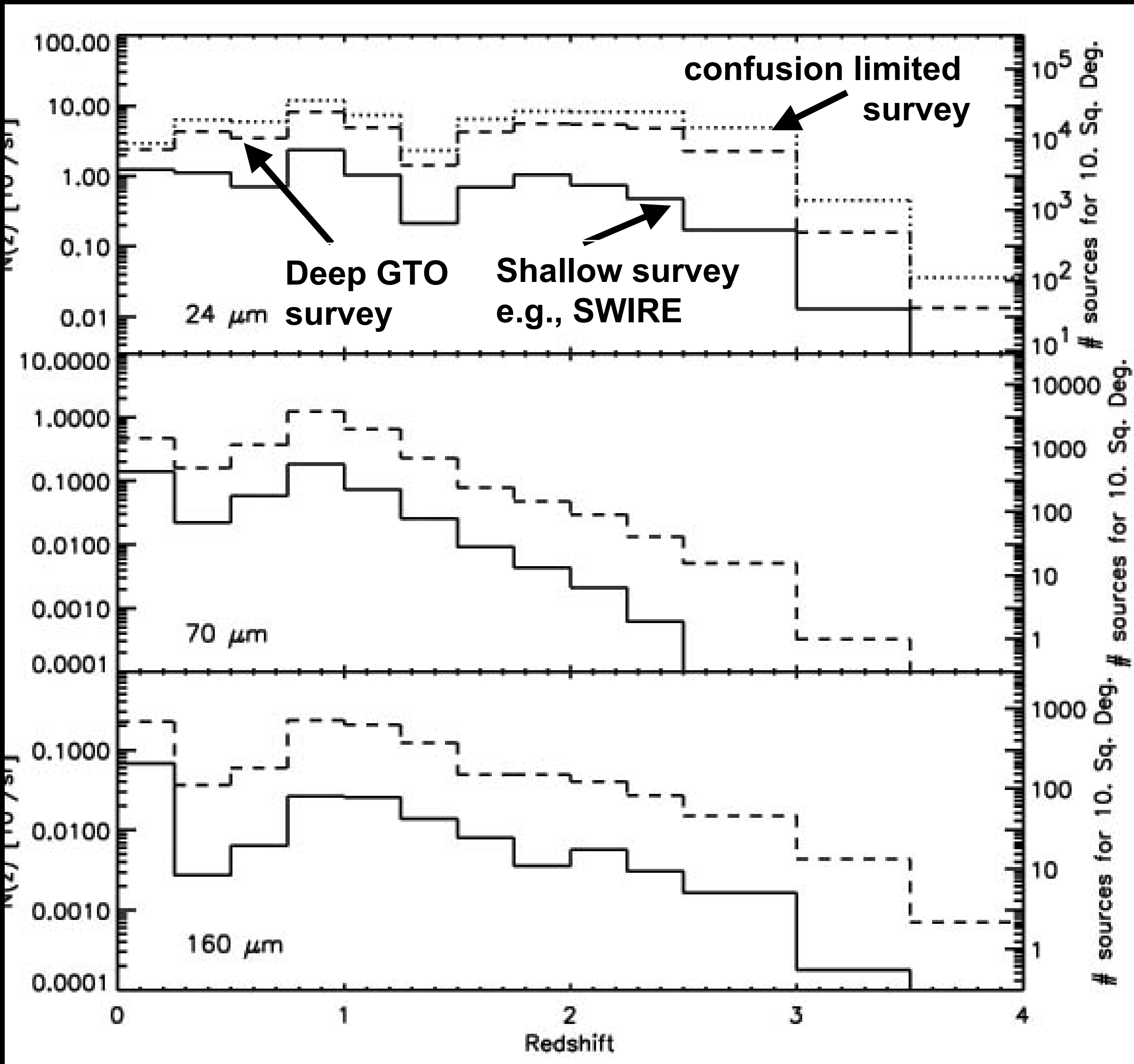



Deep Images of Infrared Sky
24μm
5’
70μm
160μm
25’

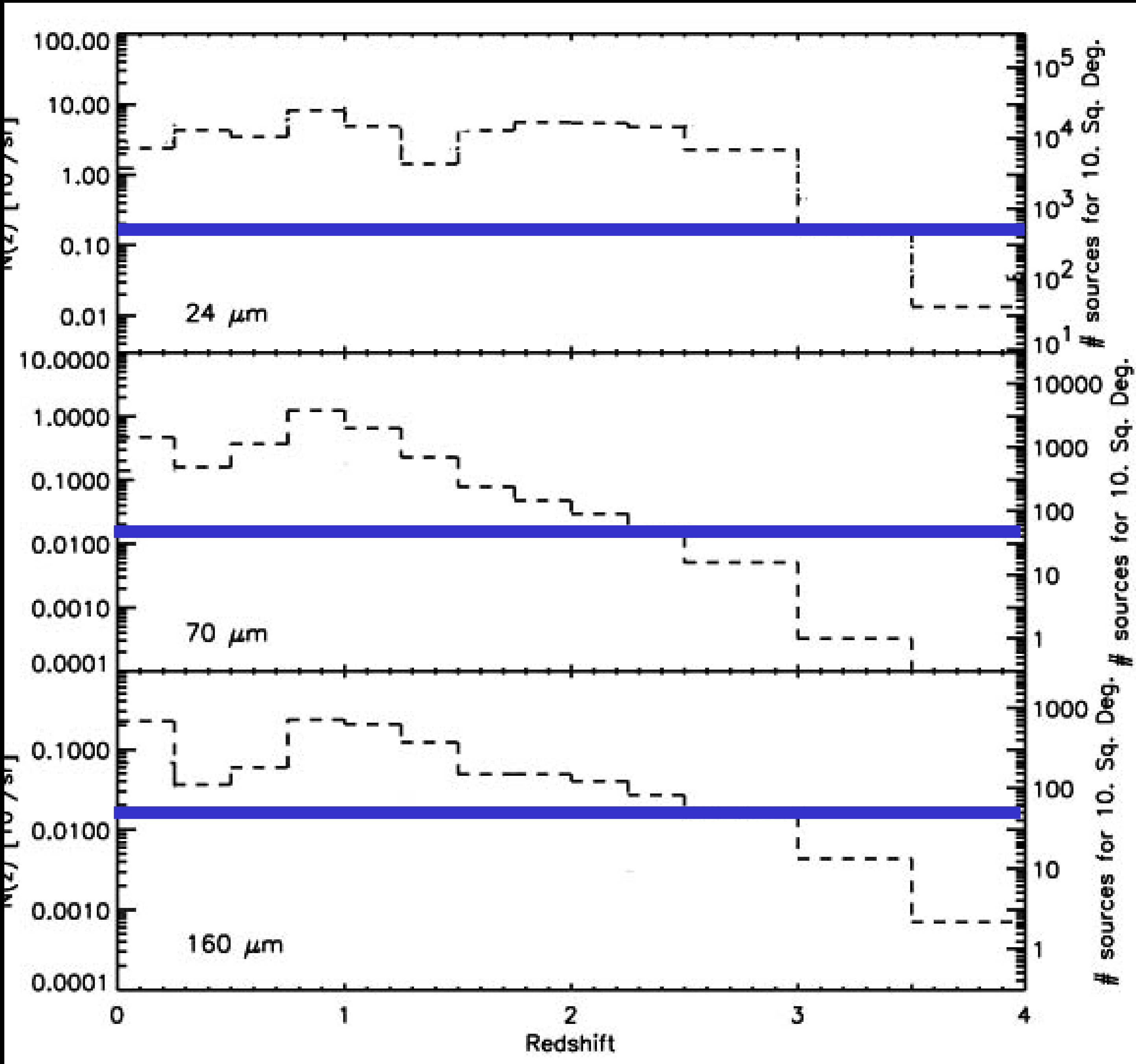
Phenomenological model (Lagache et al.) fits the number counts and predicts that MIPS will detect many galaxies to z > 2.



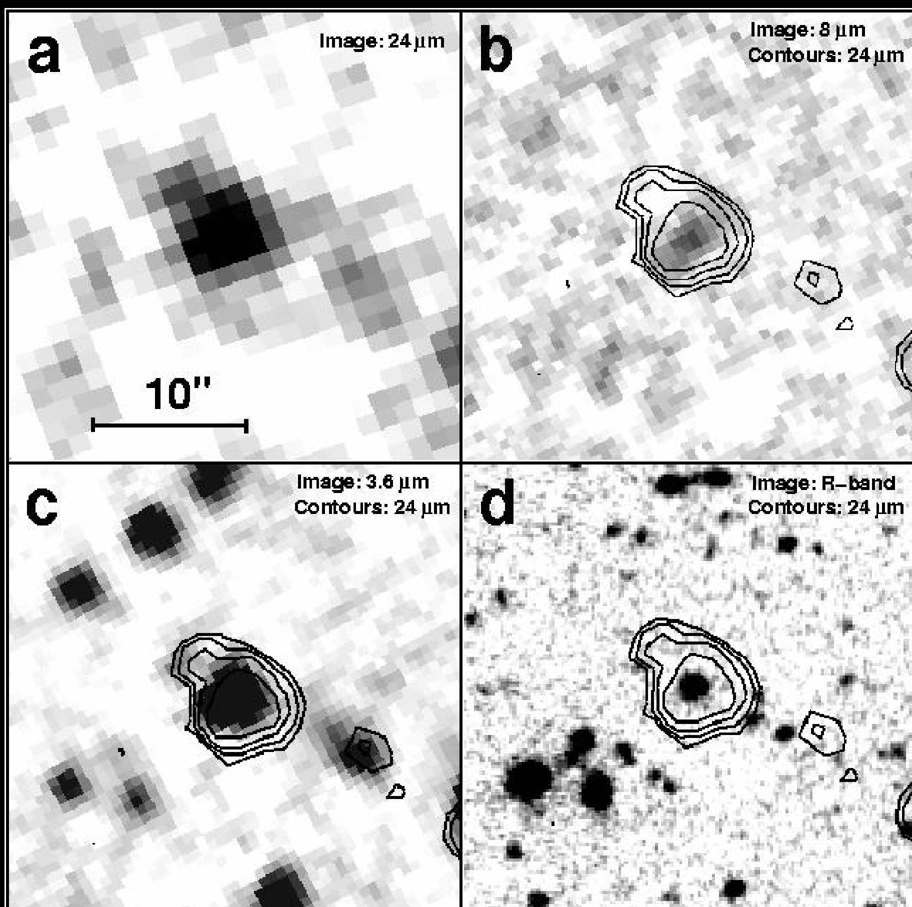
In fact,
all three
MIPS bands
are predicted
to find sources
to z ~ 3

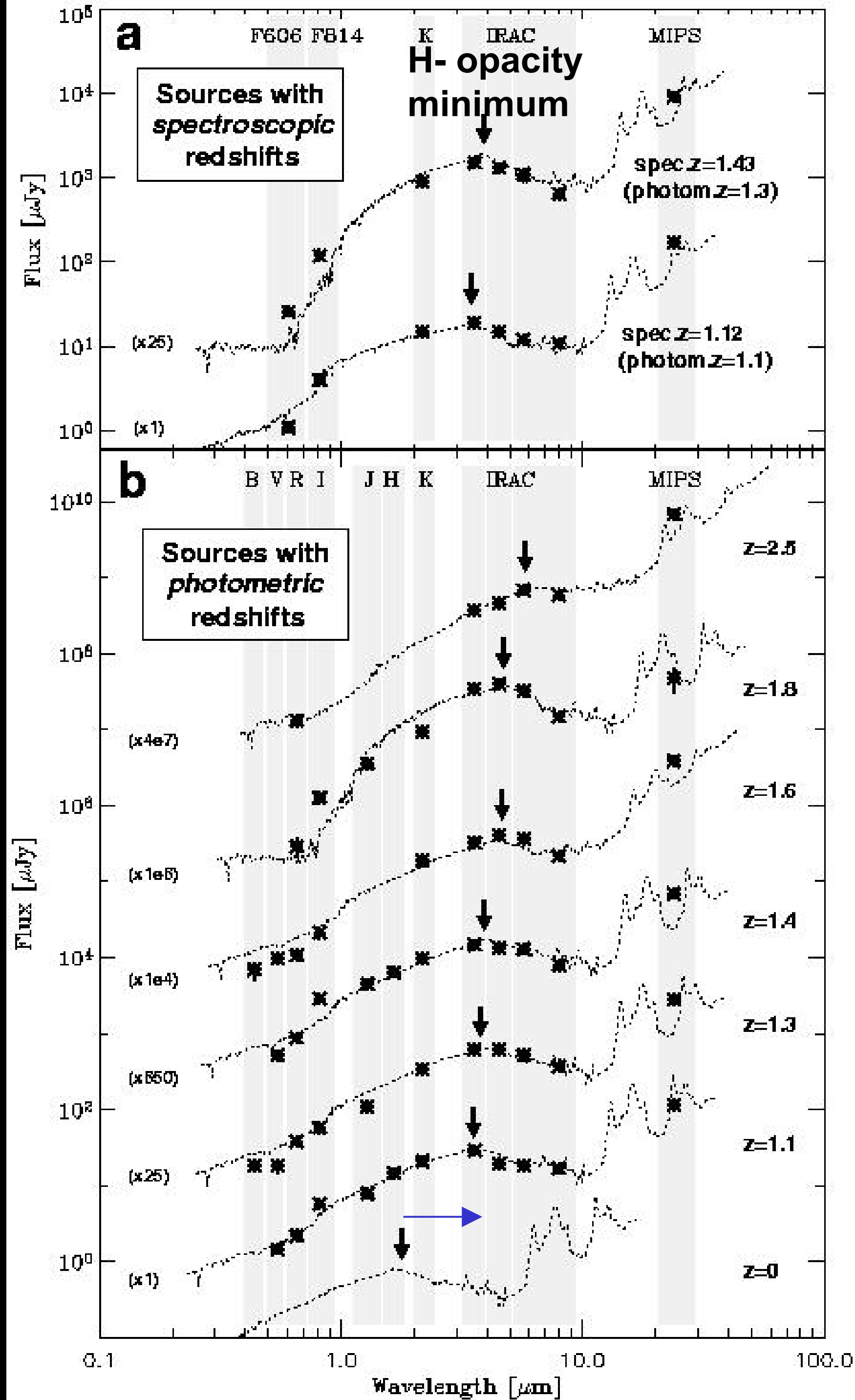


Blue lines show limits to which GTO MIPS surveys are predicted to detect 10 sources per indicated redshift bin.

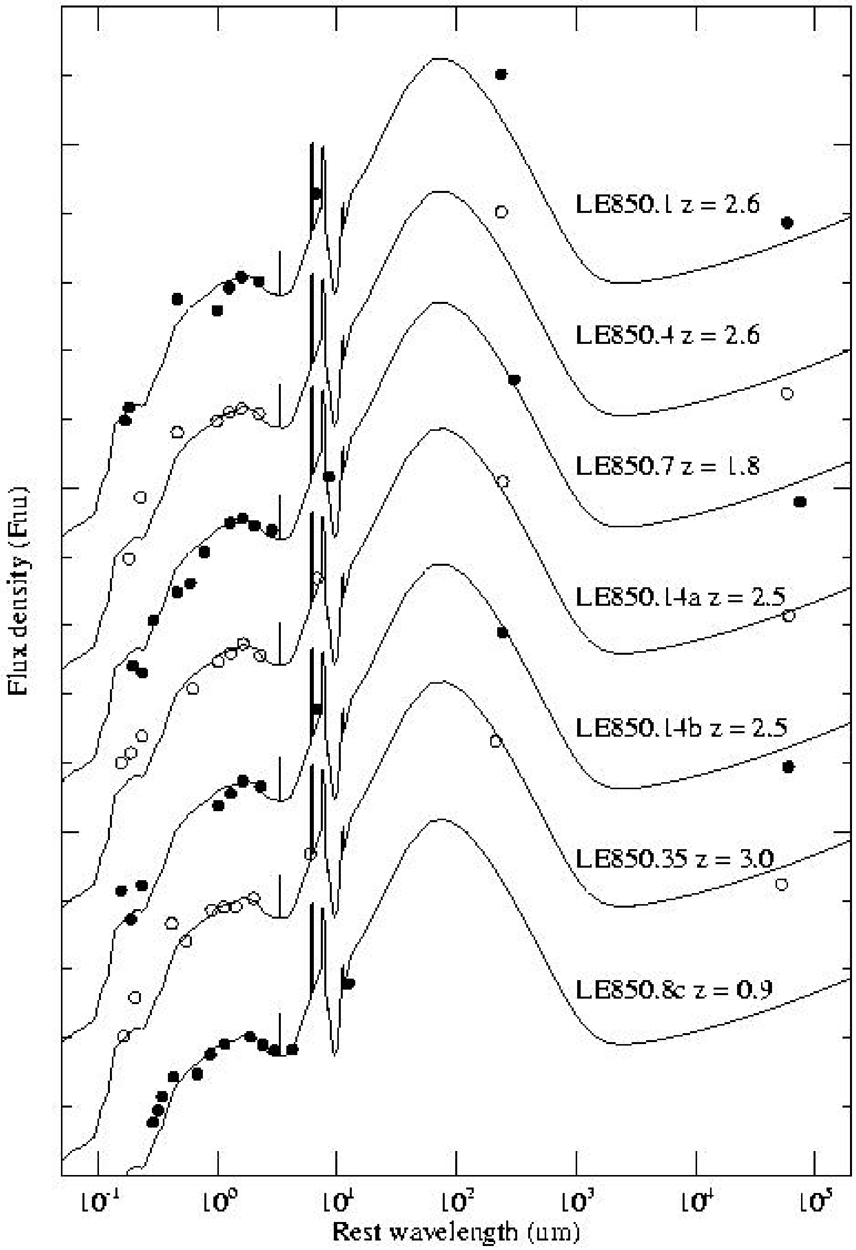


In a 5' X 5' area surveyed to ~ 100μJy at 24μm, we discovered 25 luminous infrared galaxies at an indicated z > 1 -- thirteen with luminosity > 2 X 10^{12} L_{sun}! (LeFloc'h et al.)

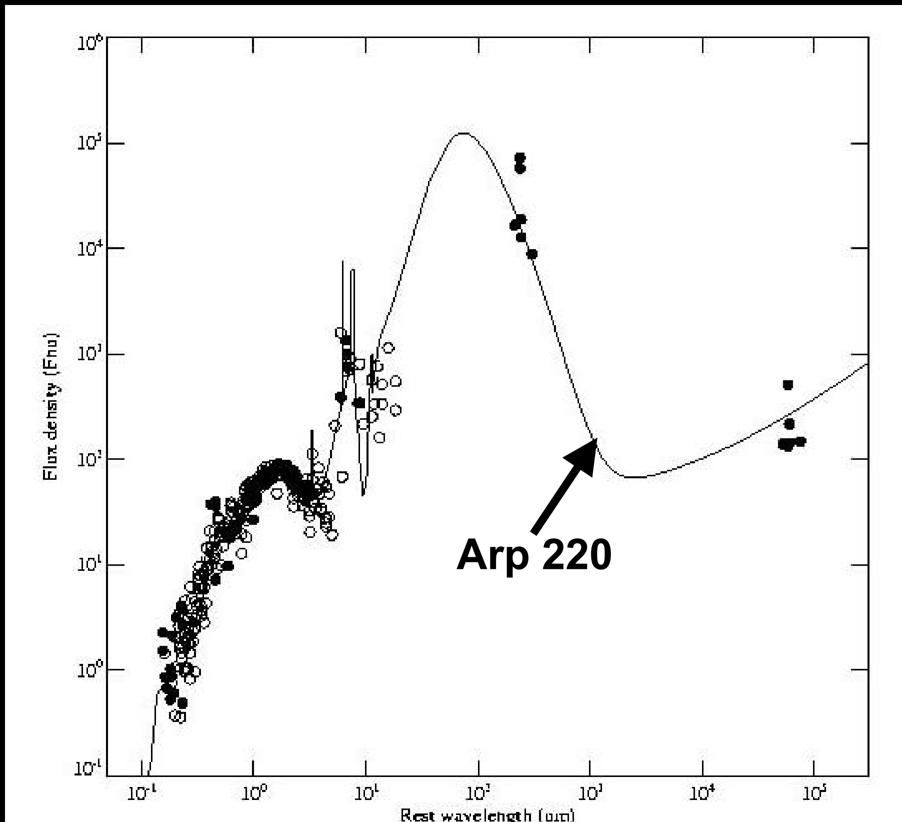


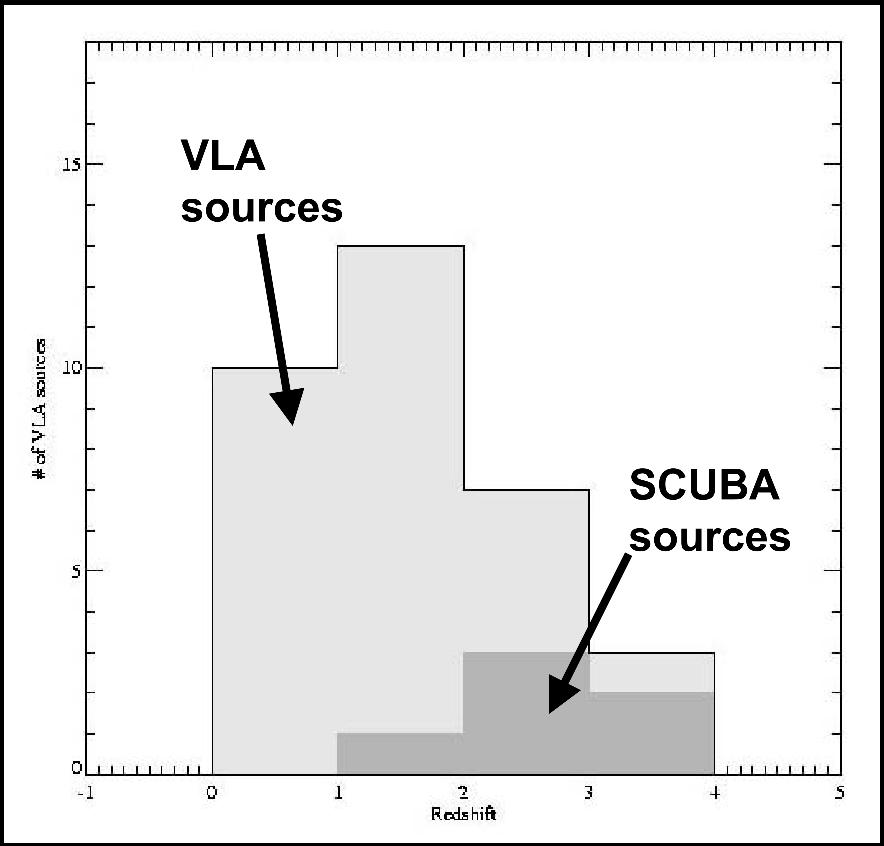


Spitzer has also obtained infrared identifications and determined photometric redshifts of 32 SCUBA and VLA detections in the same area (in the Lockman Hole).



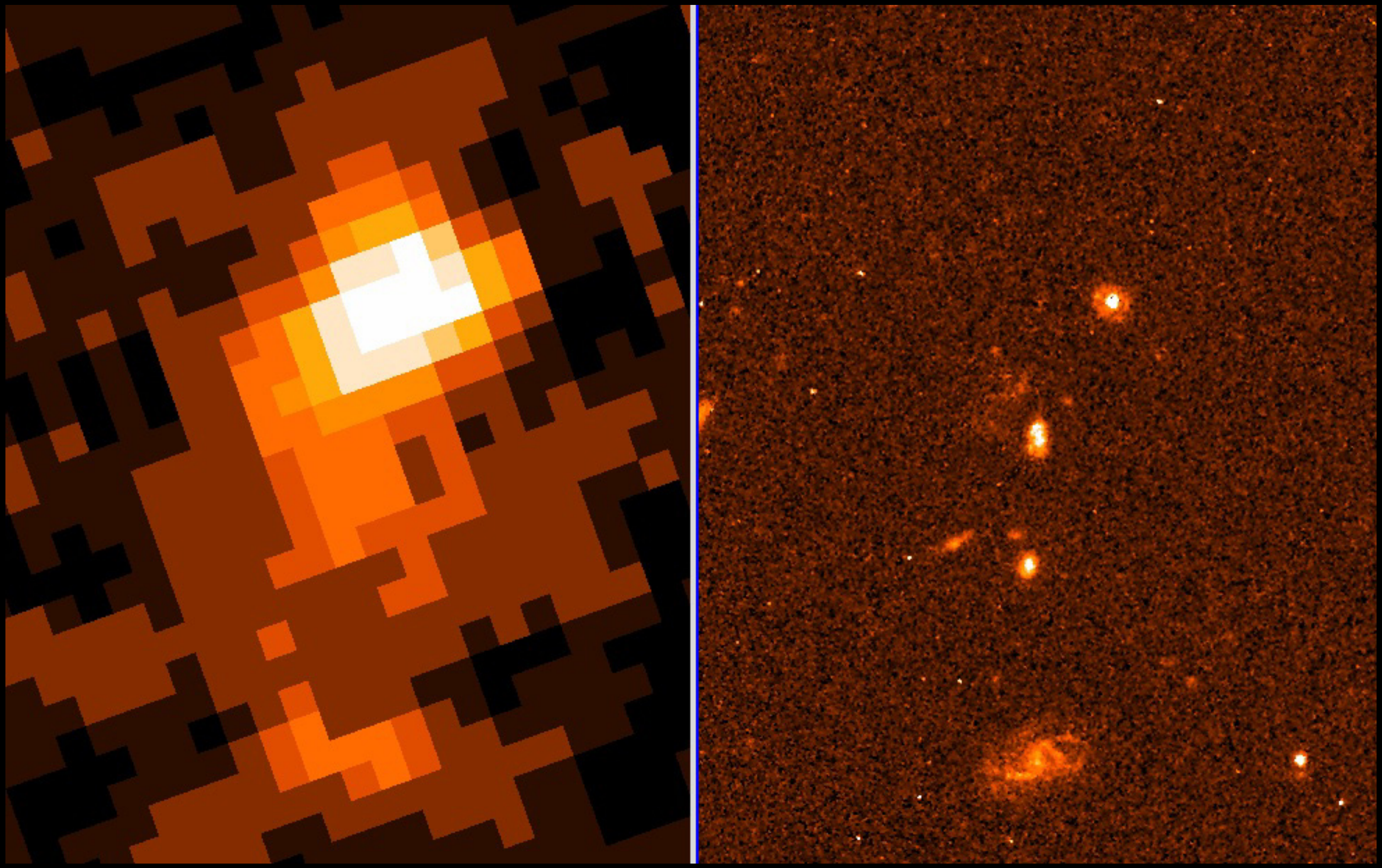
These latter objects show remarkably similar SEDs in the Spitzer - to - SCUBA measurements, and similar to Arp 220.





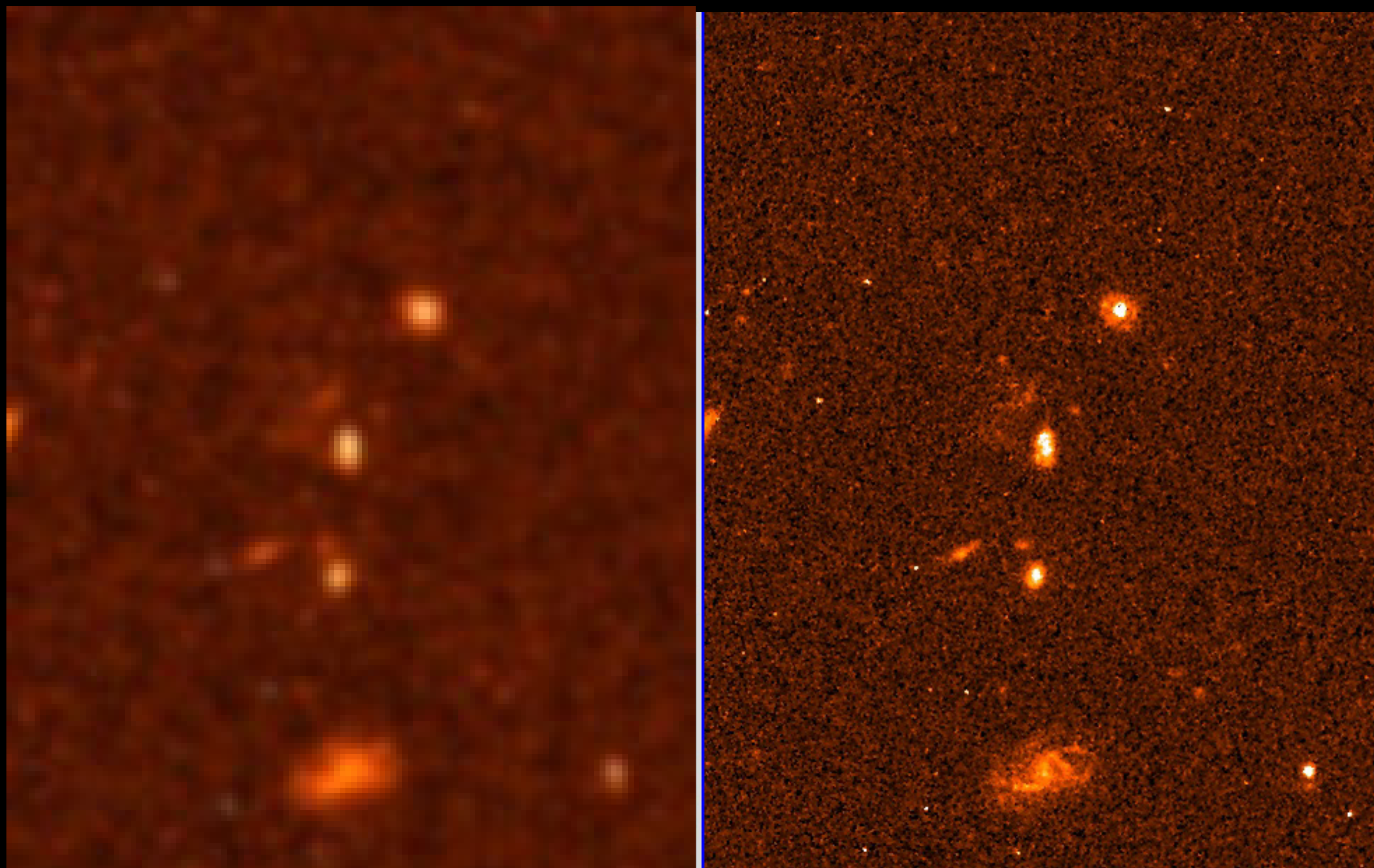
By combining these two results, for a total of more than 50 galaxies, it is possible to determine a SFR density for luminous infrared galaxies at z > 1. The resulting SFR is similar to the standard Madau SFR density and implies that the true total SFR from z ~ 1 to z ~ 3 is at least twice as high as deduced from optical studies, with the infrared component concentrated into very luminous galaxies.

However, Spitzer will provide relatively little additional information about the morphology and even identification of the detections.



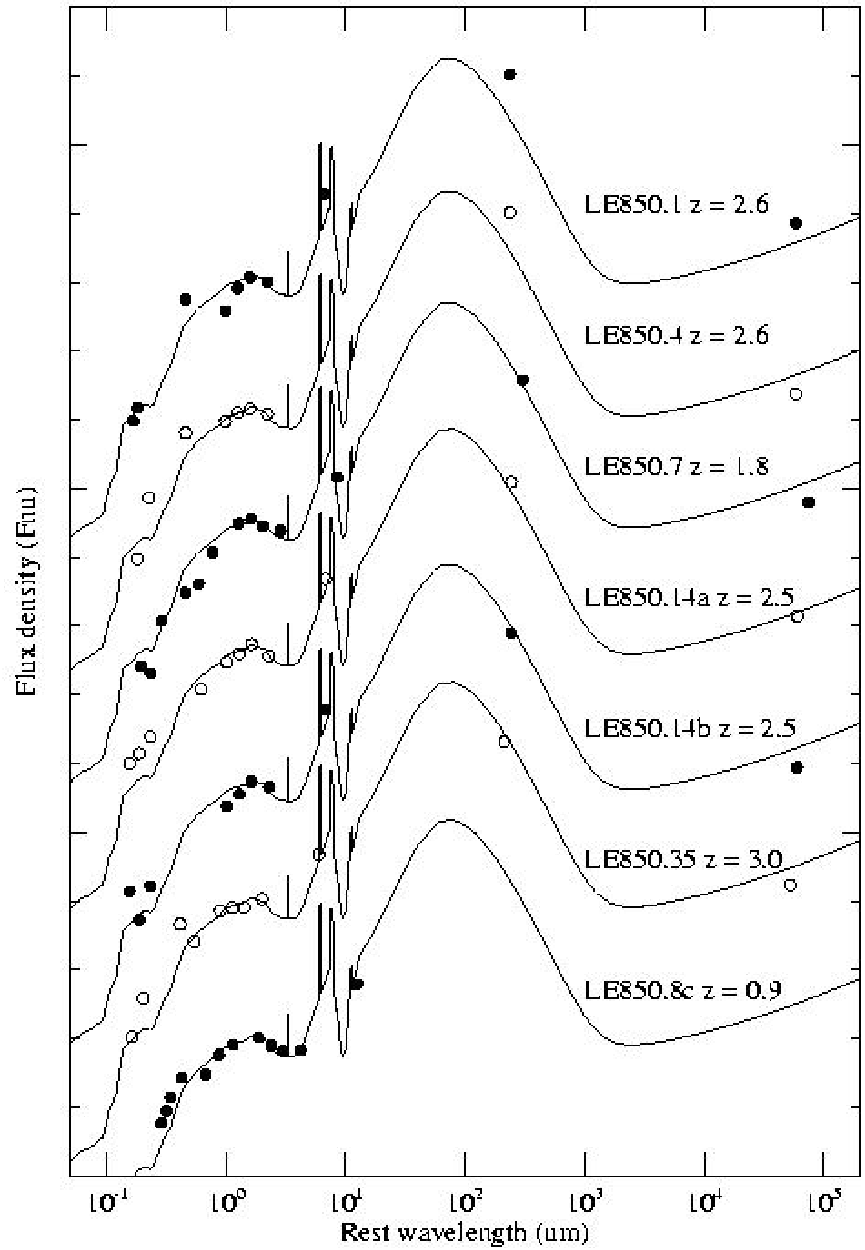
To left, Spitzer 24μm; to right, WFPC

SAFIR will fill this need: to left, SAFIR resolution at 40μm or MIRI resolution at 24μm to right HST @ 0.7μm ~ JWST @ 2μm



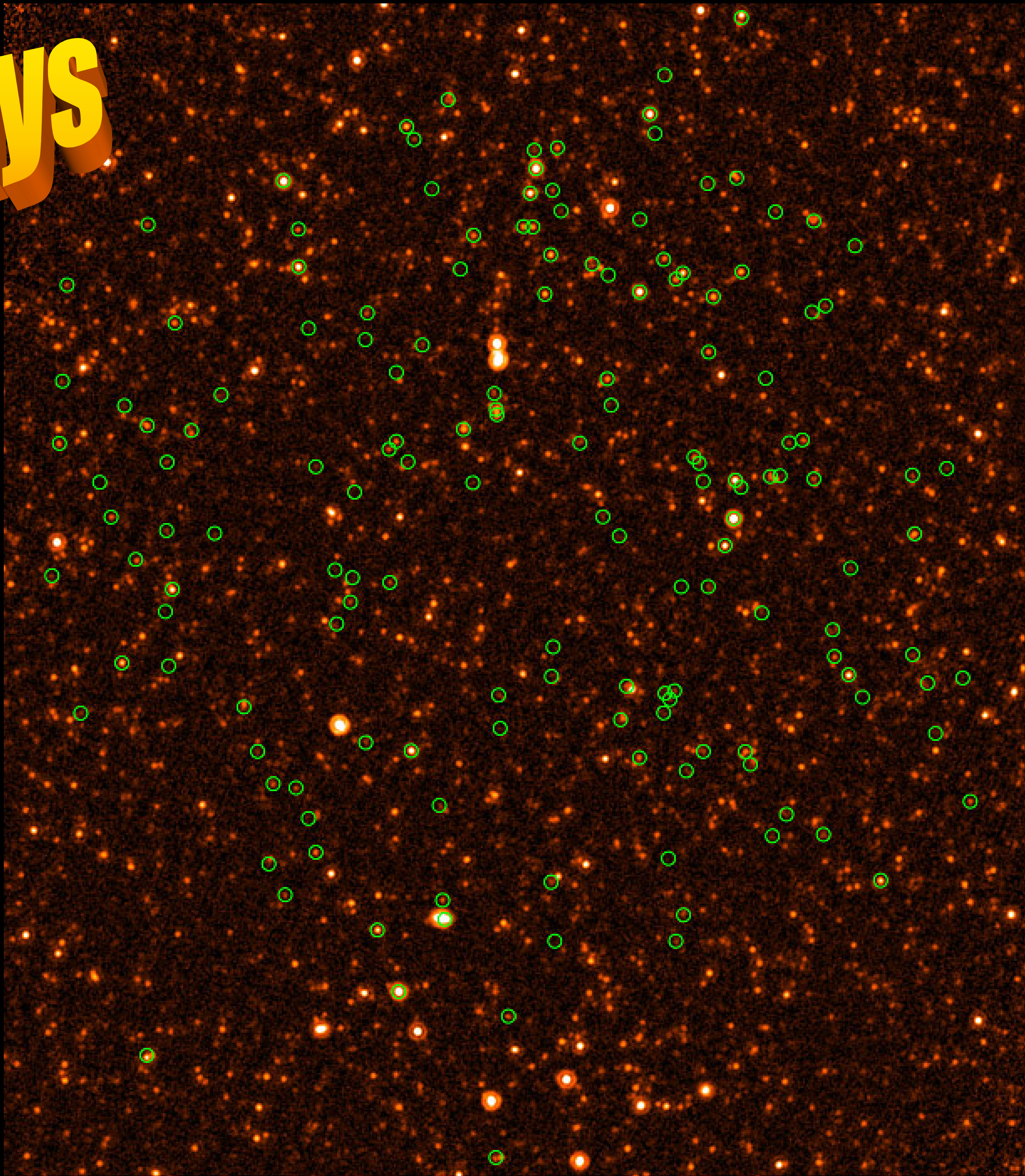
The 1 - 12μm photometry will be critical to estimate redshifts and stellar populations.

NIRCam and MIRI working together are the only way to make the necessary measurements

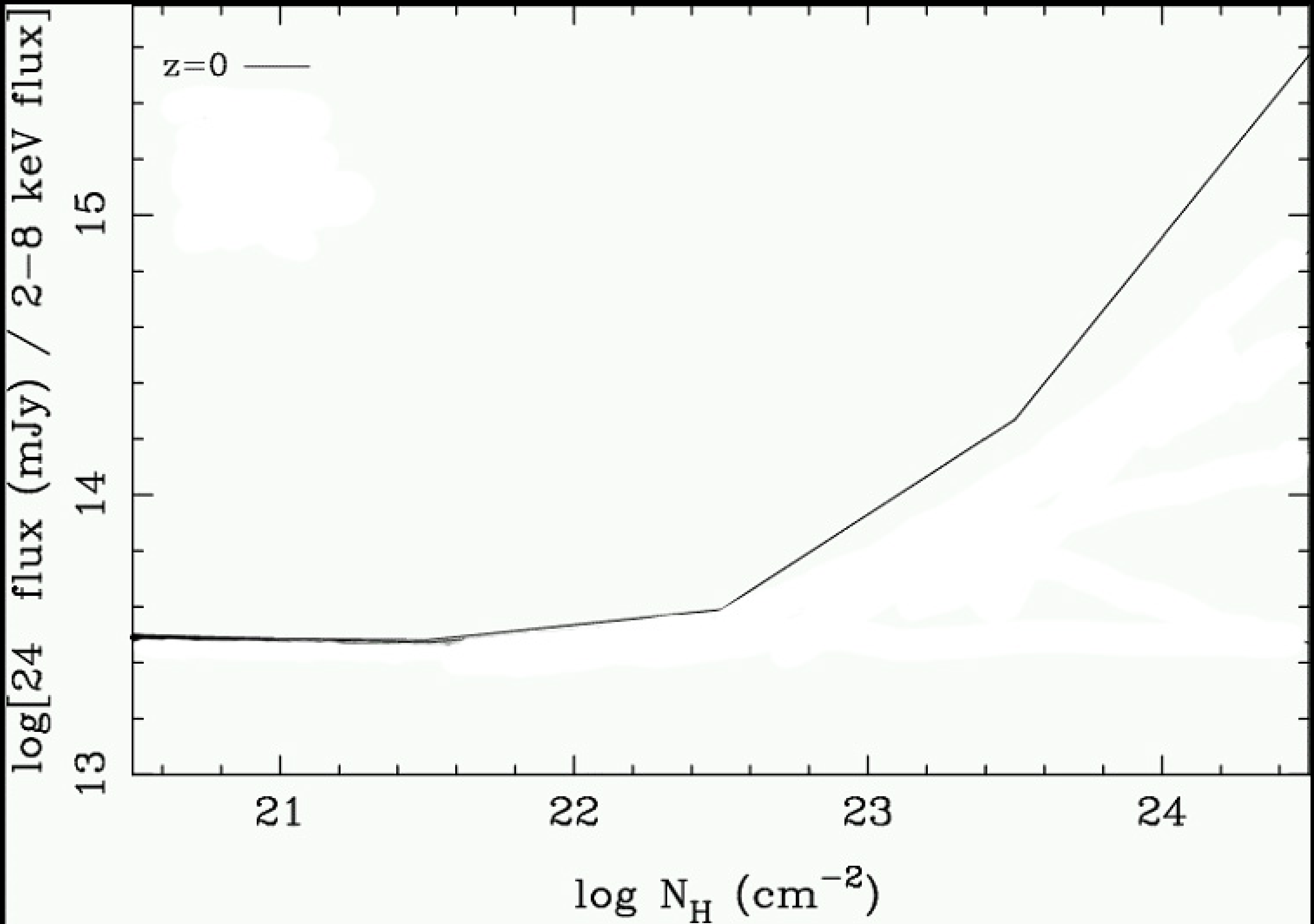


MIPS & X-Rays

Sources from Chandra Deep Field - South Megasec exposure (green circles) superimposed on the MIPS 24μm image of CDF-S (62% of HX sources are detected at 24μm).

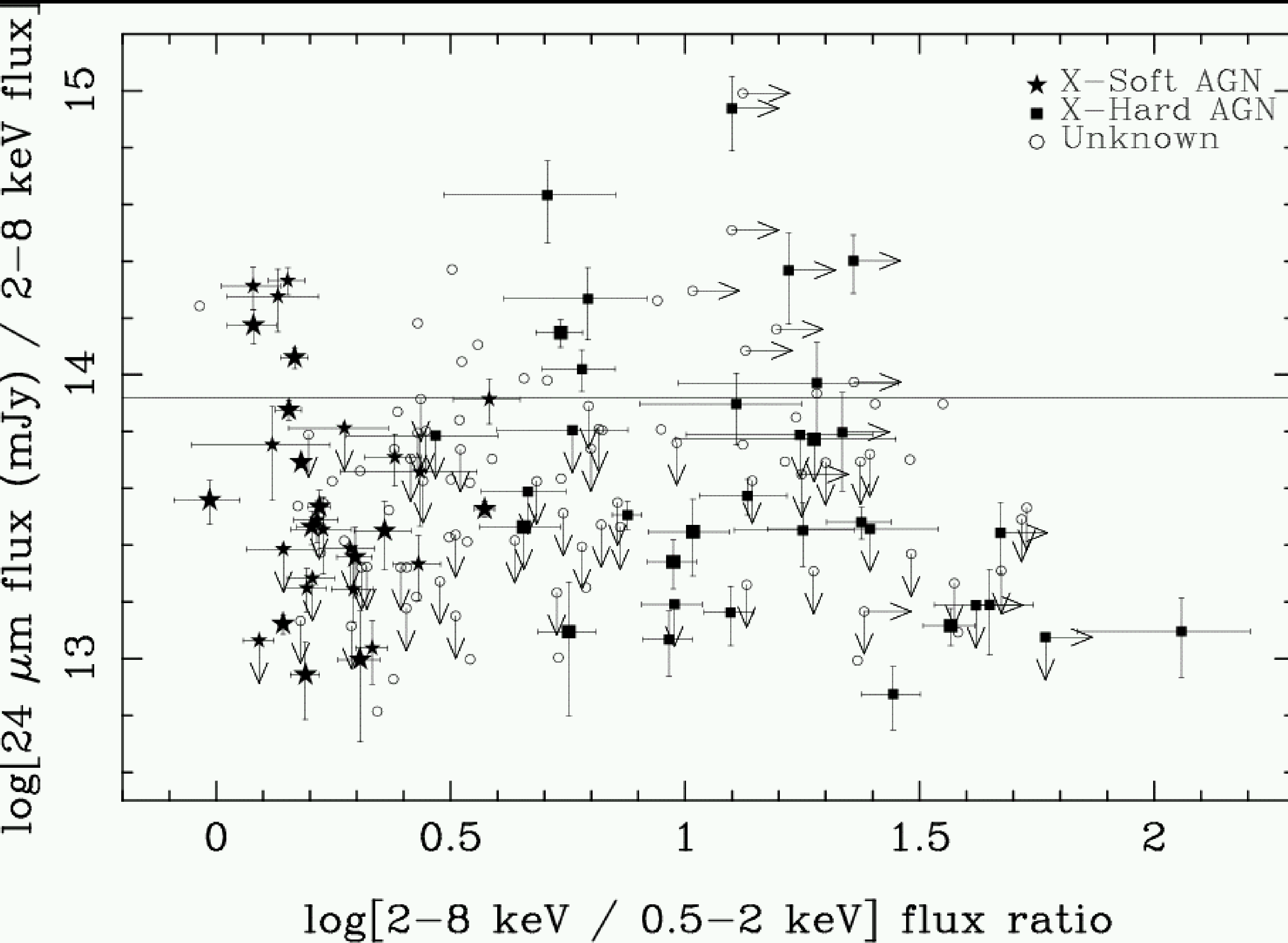


SED models indicate that the ratio of 24μm to hard X-Ray should increase with increasing absorption column, associated in the unified model with Compton-thick sources. Such objects are believed to be numerous at high redshift and responsible for the X-Ray background.

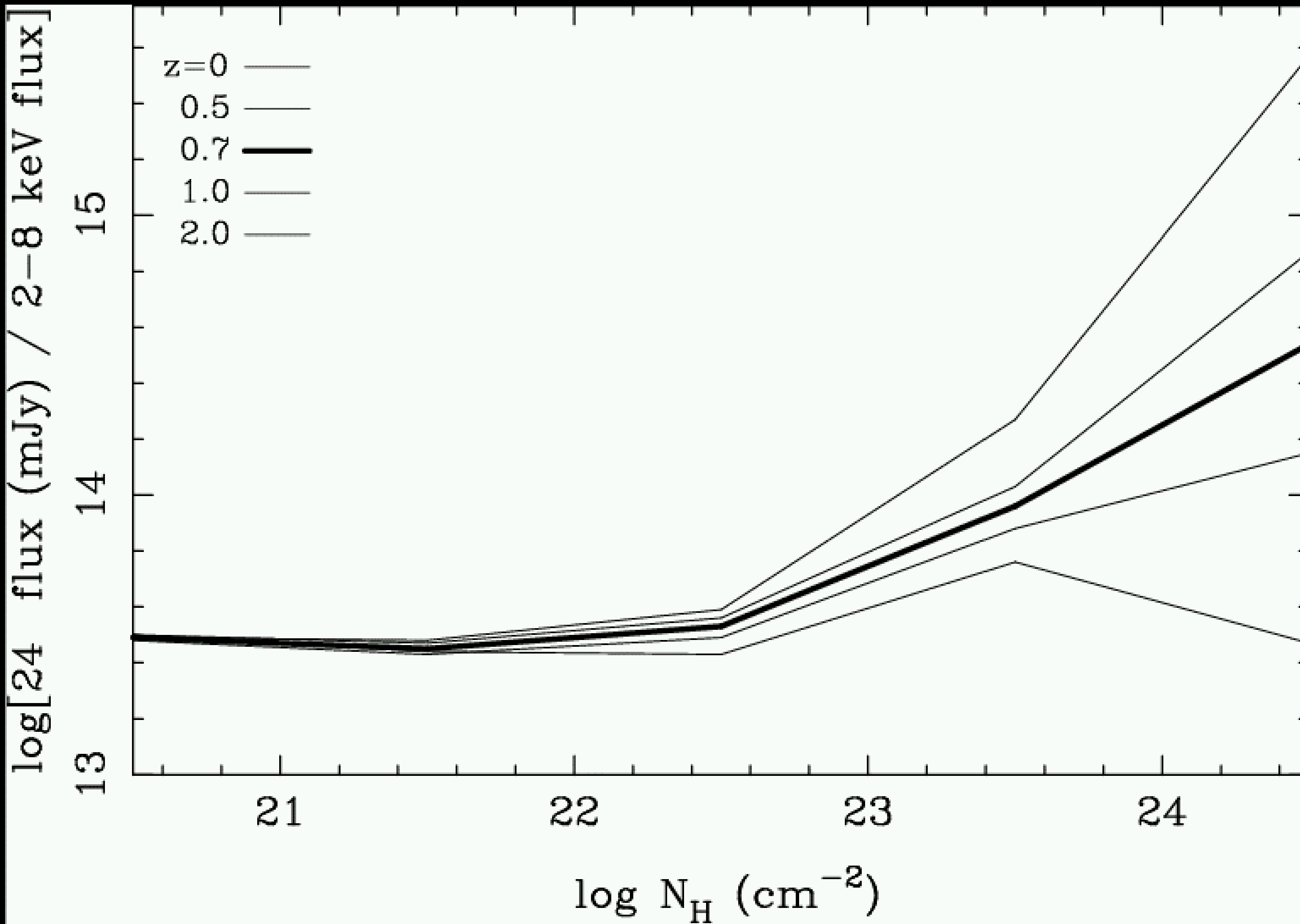


Surprisingly, there is no trend of increasing 24μm/HX with increasing X-ray hardness (expected if absorbed energy were re-radiated in the IR). Instead, there may be a population with very hard x-rays, weak at 24μm.

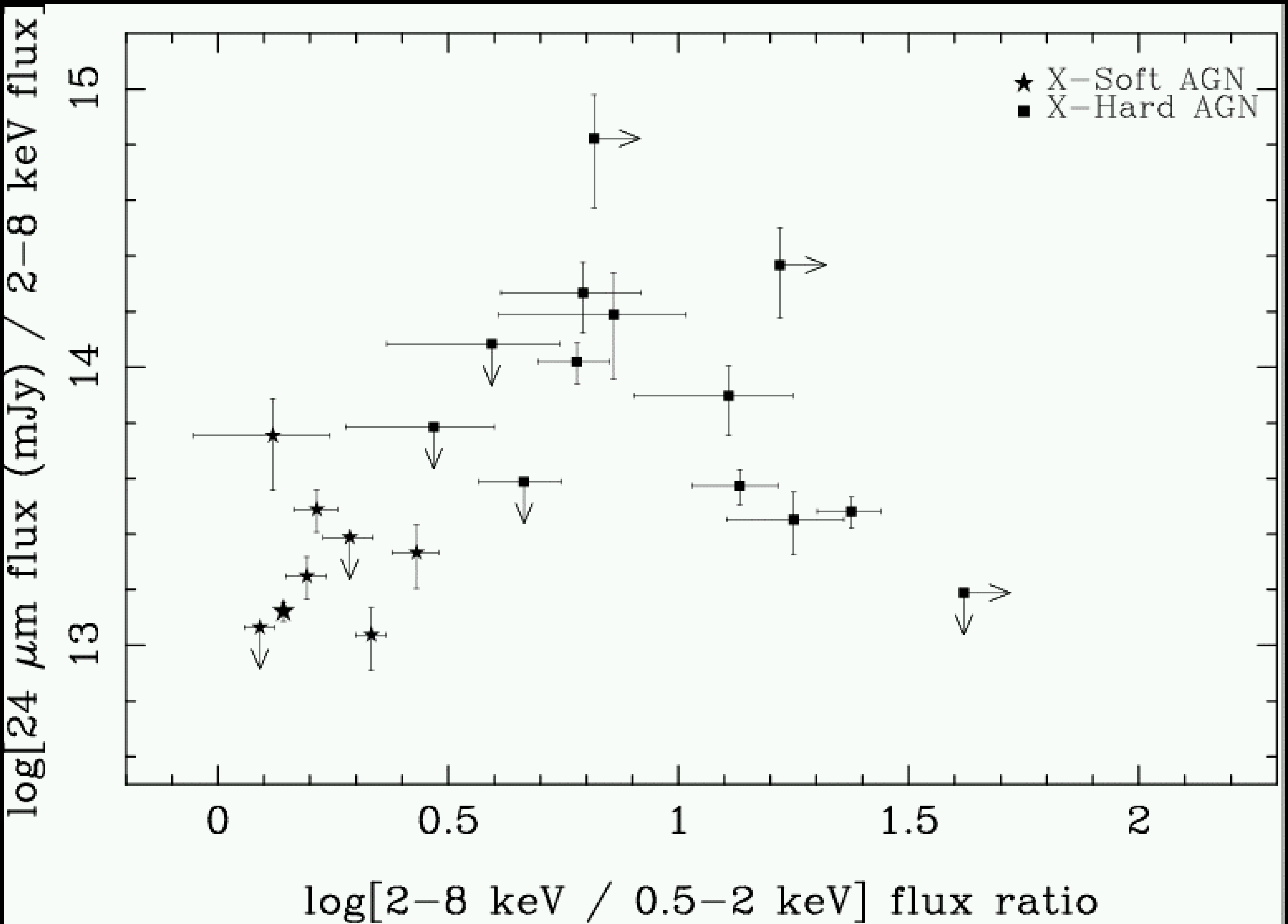
(Rigby et al.)



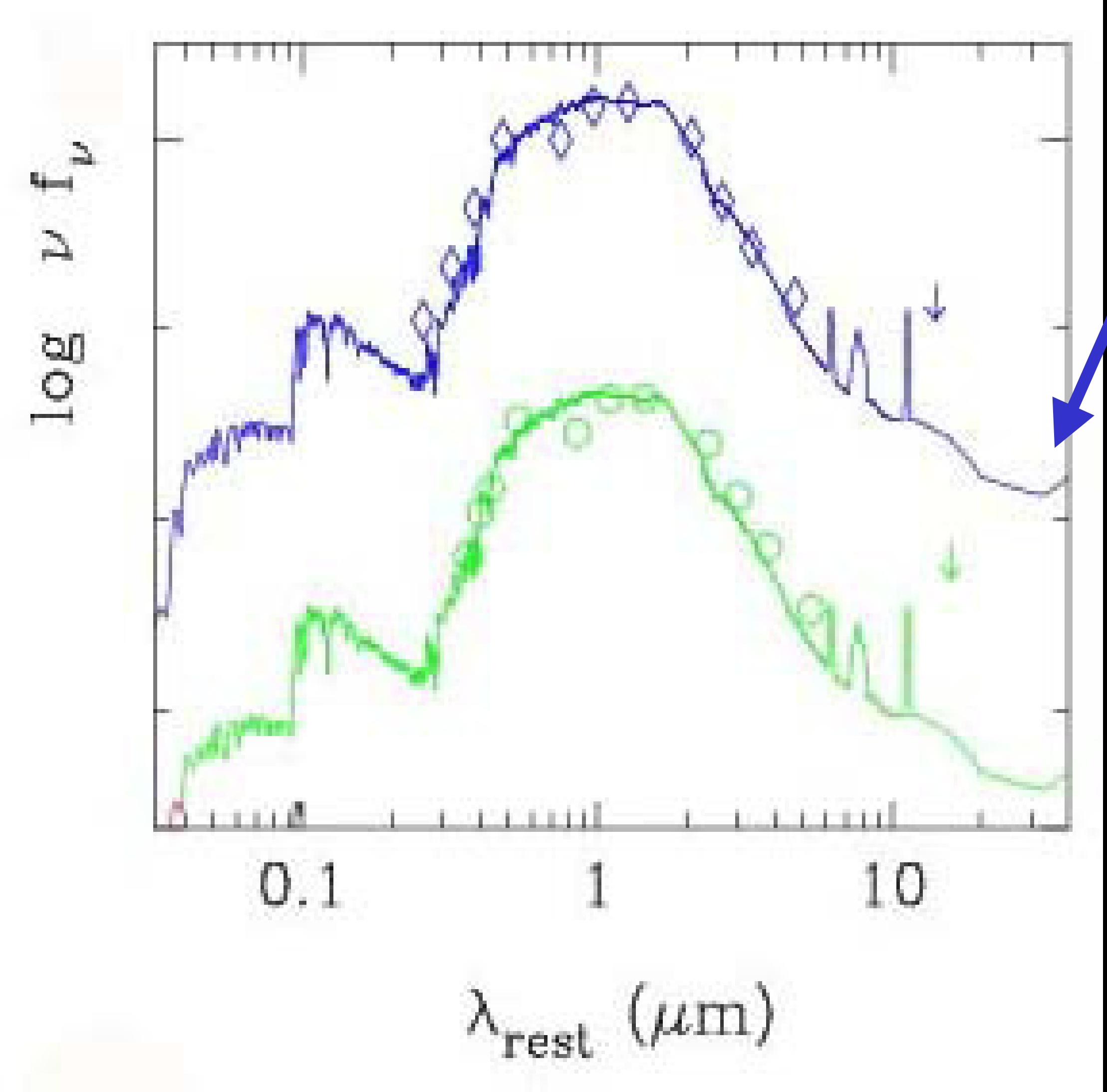
At z >> 0.7, the effect becomes small because the rest frame HX has moved to ~ 10keV or even higher energies.



However, even a subsample selected to be at z = 0.70 ± 0.05 does not show the expected effect - instead, it has a number of the hard x-ray, weak infrared type of object.



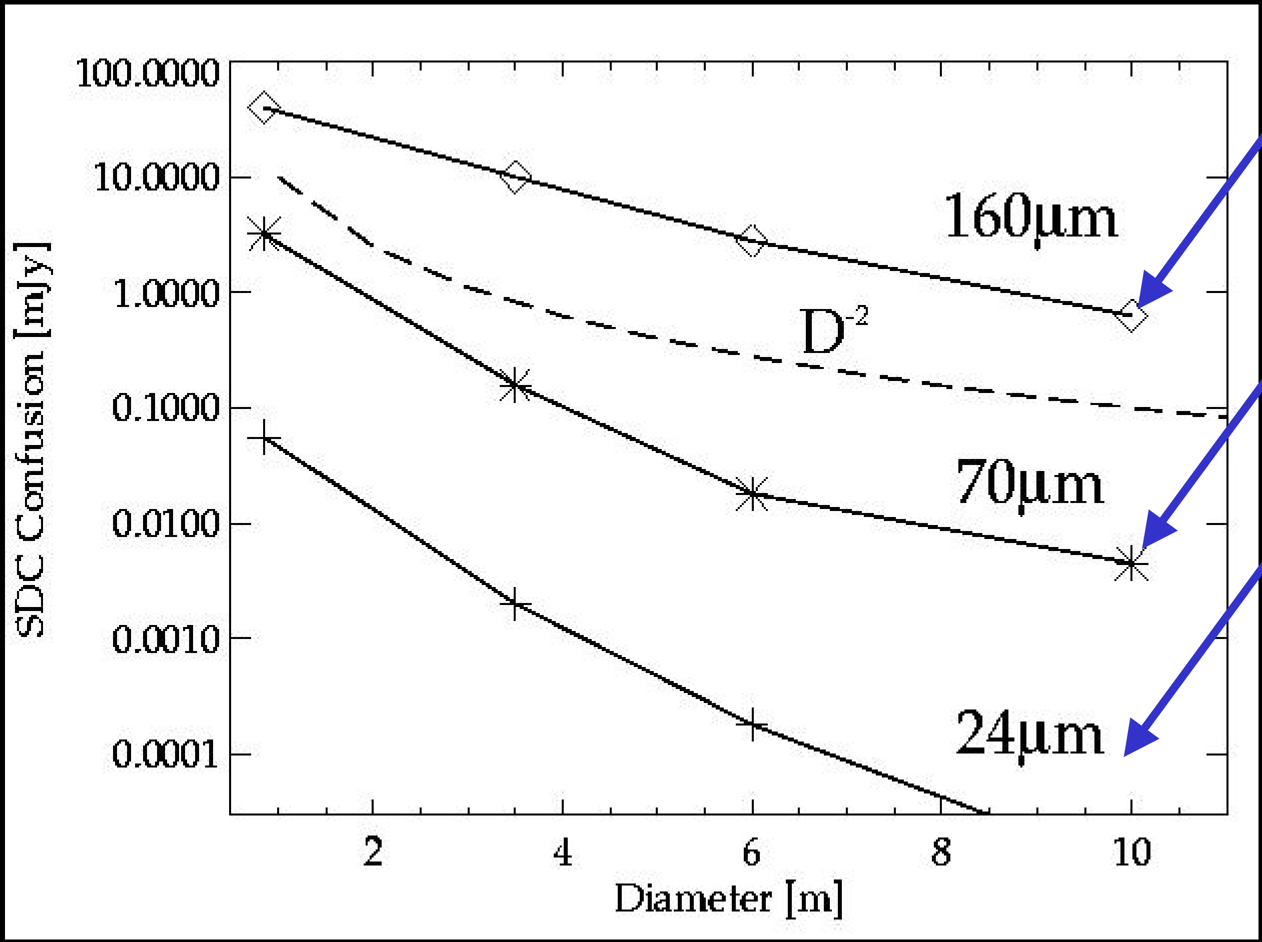
A problem for SAFIR:



Greater sensitivity in the far infrared is needed to probe where the energy is going in obscured AGN

SAFIR imaging detection limits are an incredible advance over Spitzer

Confusion effects get "resolved out." (from Dole et al.)

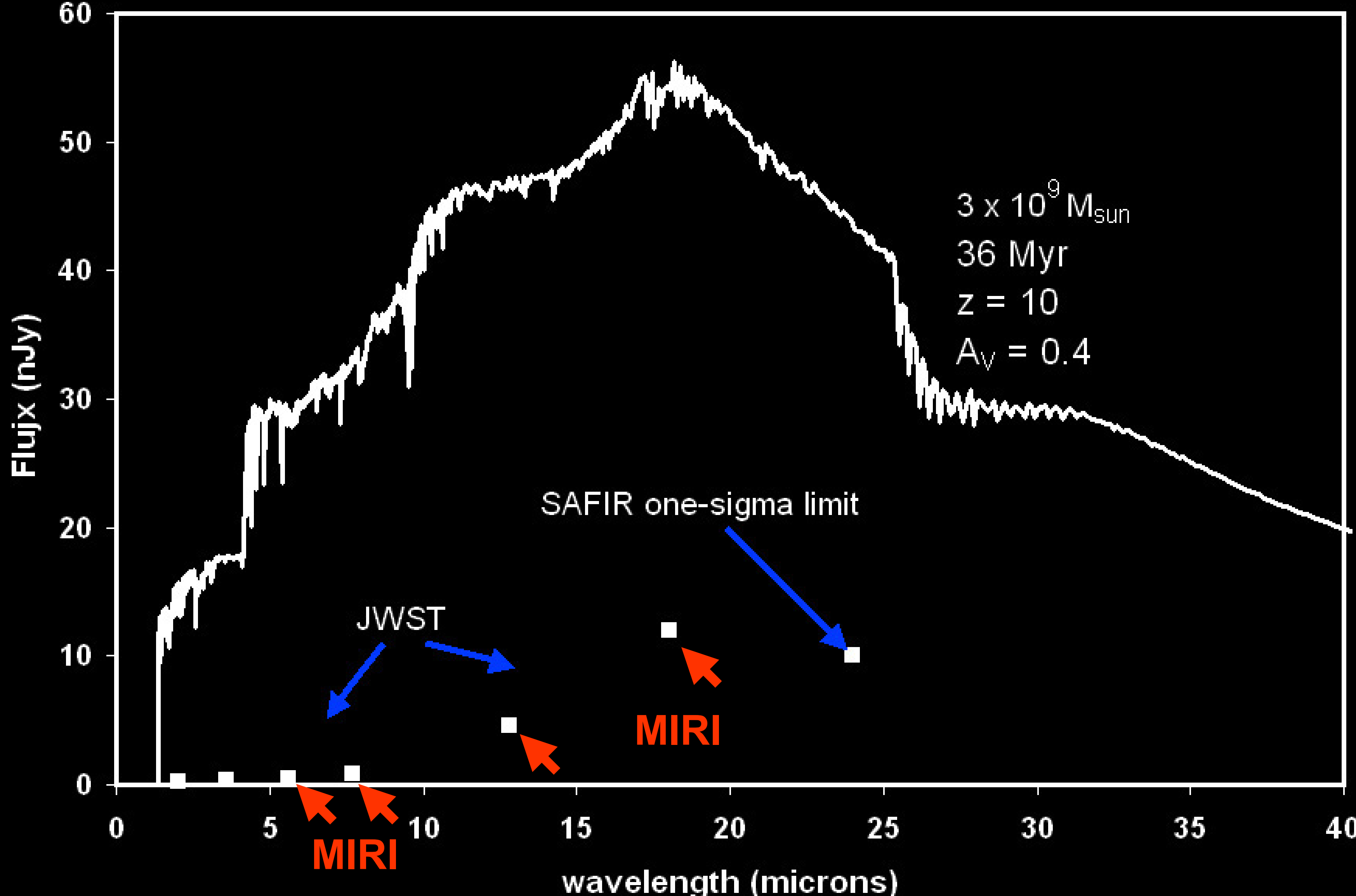


0.6mJy (100 times lower than Spitzer)

4µJy (1000 times lower than Spitzer)

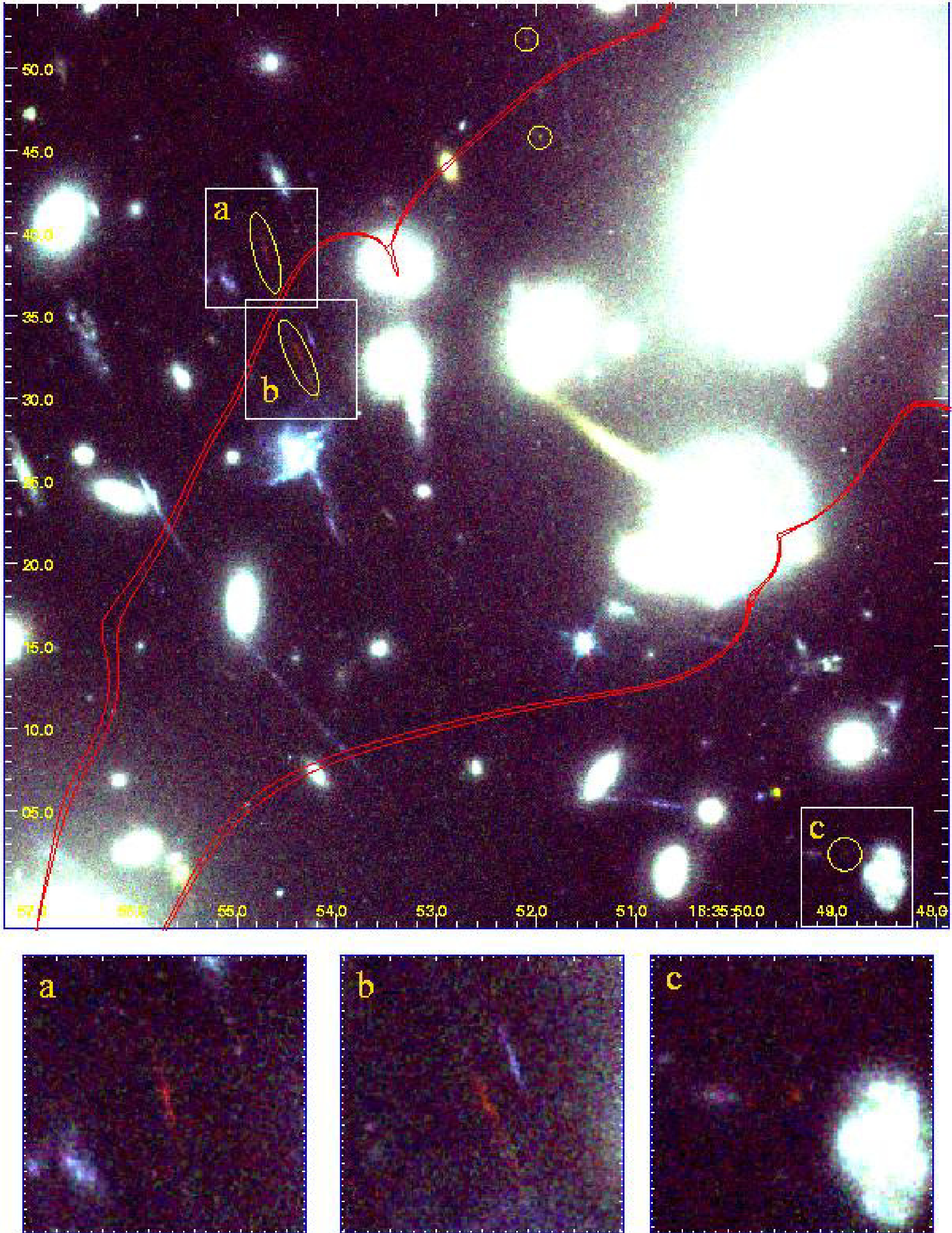
10nJy (100,000 seconds integration; 1000 times lower than Spitzer, 100 times lower than JWST)

With the SAFIR sensitivity, we could measure *photospheric* emission in galaxies at z = 10!!

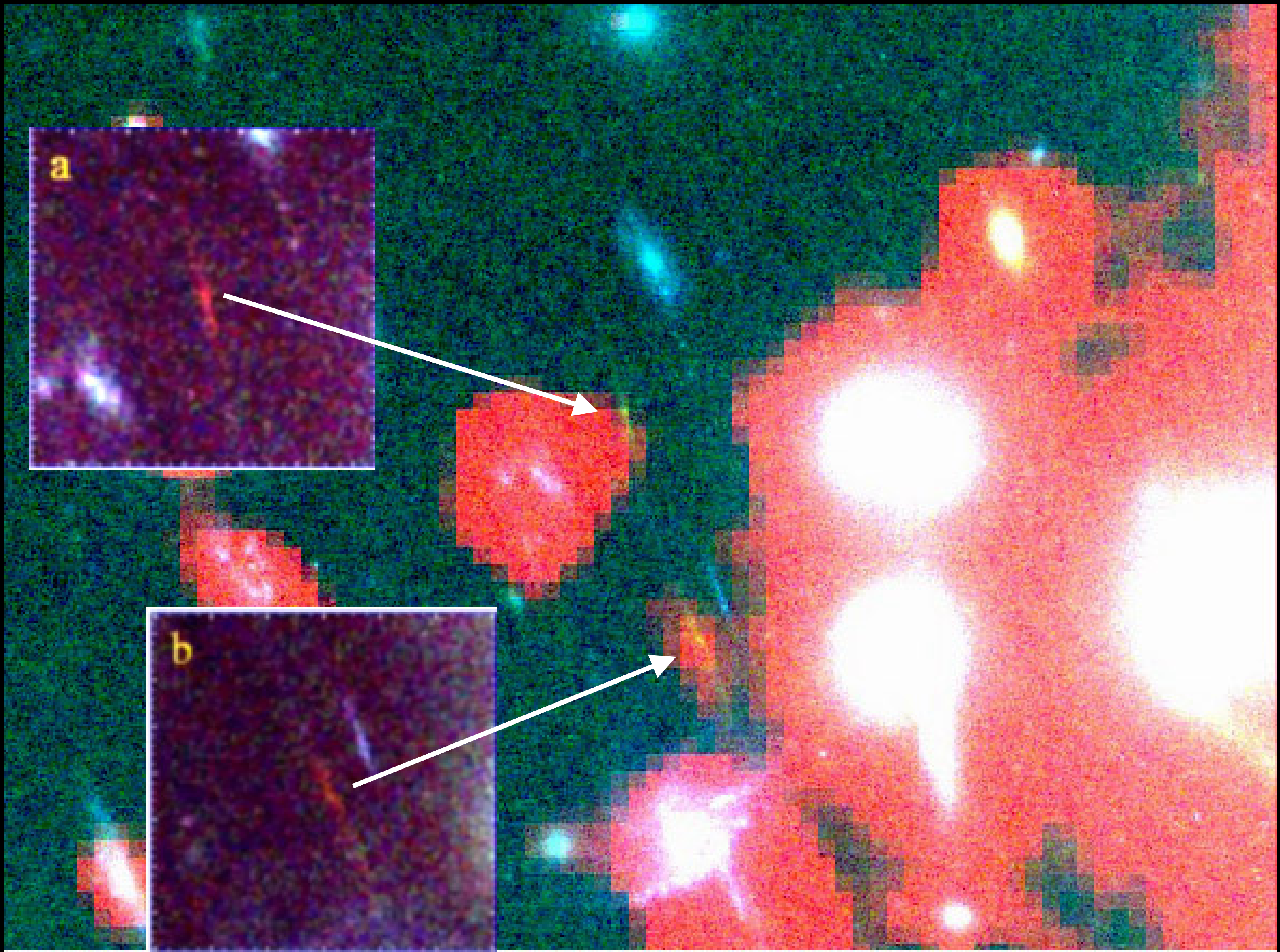


Will there be any galaxies like that hypothetical one to measure?

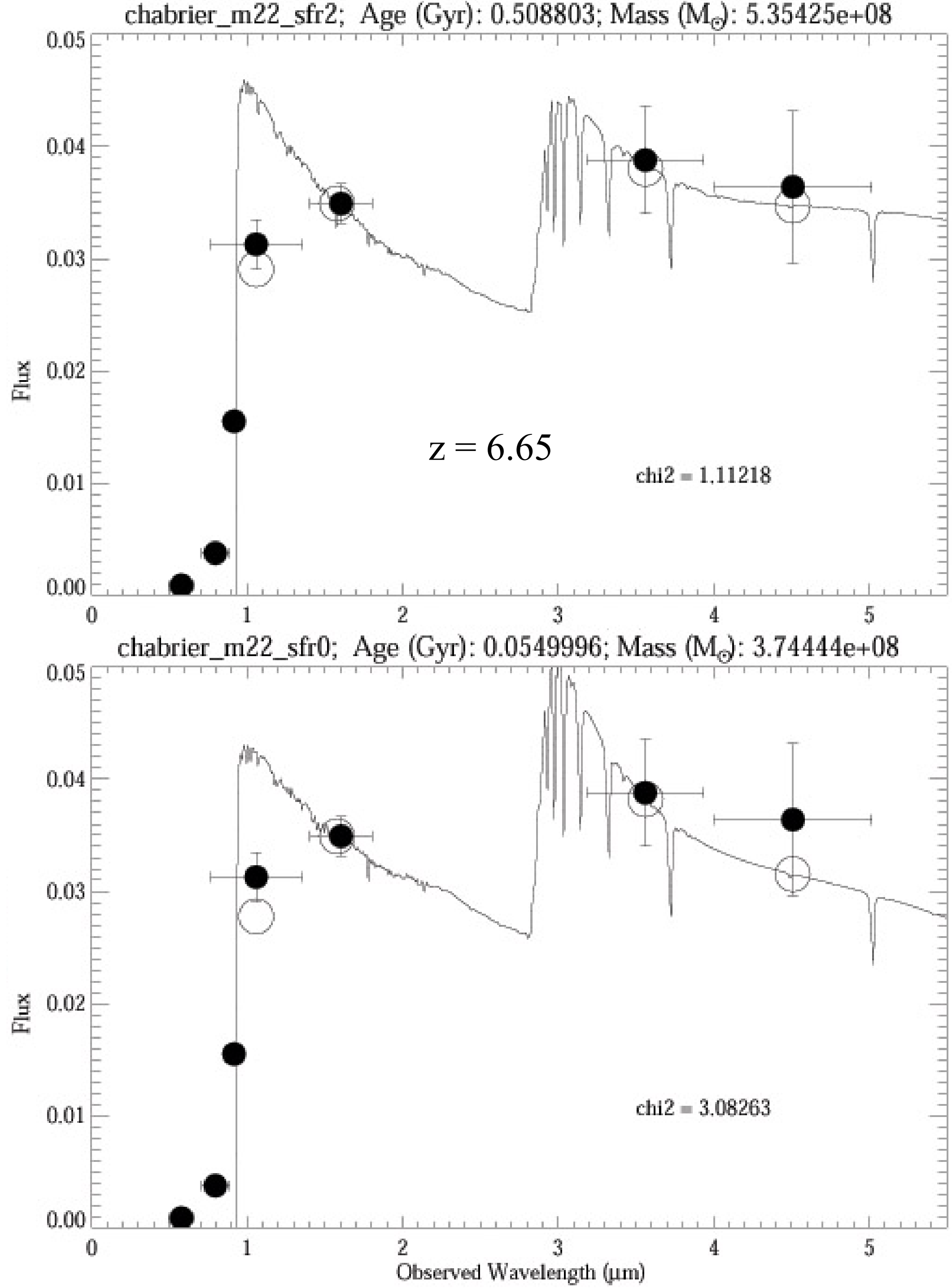
a, b, and c are lensed images of a suspected z = 7 galaxy behind Abell 2218.



Spitzer detects the galaxy at 3.6 and 4.5μm.
Blue is HST, red is 4.5μm.



Fits to the photometry indicate a stellar mass of about 4 x 10^8 M_{sun}



A similar lensed galaxy at z = 10 could be measured with SAFIR at 24μm